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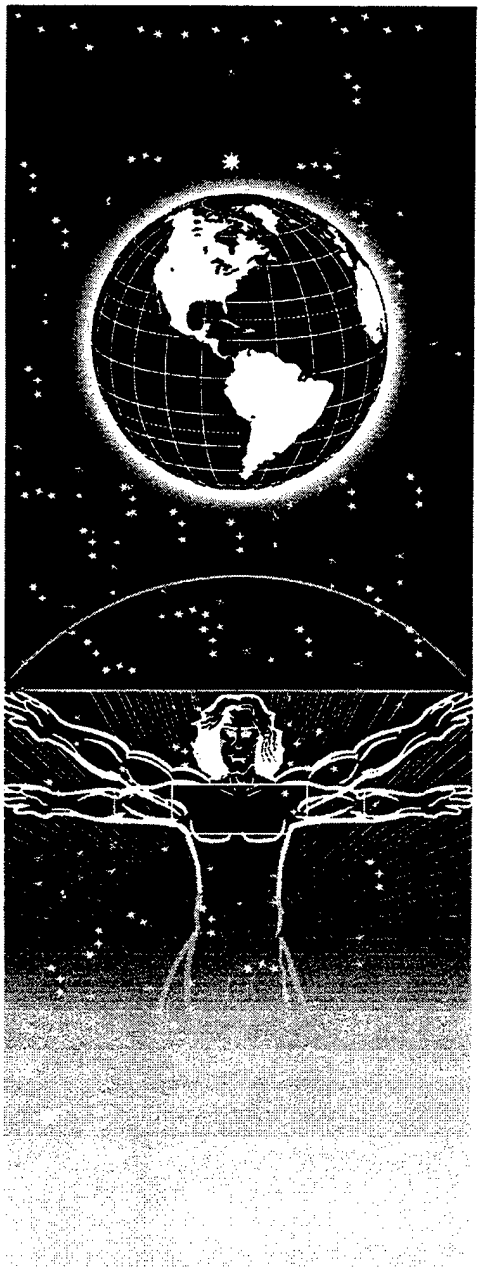

UNITED STATES AIR FORCE RESEARCH LABORATORY

RESEARCH AND DEVELOPMENT OF ADVANCED LIFE SUPPORT EQUIPMENT

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February 1999

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The Office of Public Affairs has reviewed this report, and it is releasable to the National Technical Information Service, where it will be available to the general public, including foreign nationals.

This report has been reviewed and is approved for publication.

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13. ABSTRACT *(Maximum 200 words)*
The purpose of this effort was to provide research and research support to on-going RDT&E efforts in the following areas: The effect of physical conditioning on acceleration tolerance/endurance; Female G tolerance/endurance; Effect of varied periods of acceleration layoff on acceleration tolerance/endurance; Effect of crewmember posture and position on acceleration tolerance/endurance; Use of animal models for human acceleration tolerance/endurance; Life support equipment development laboratory; Testing of life support equipment, subatmospheric research; Molecular sieve technology; Spatial disorientation (SD) countermeasures research; Sustained operations research; Biomedical laboratory operation and support; and Task order requirements. This final report provides summaries and accomplishments including citations and abstracts for the publications documenting the results of the specific efforts.

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PREFACE

KRUG Life Sciences Inc. (KLSI) has provided technical support to accomplish "Research and Development of Advanced Life Support Equipment" for the Crew Technology Division at Brooks AFB, Texas under USAF Contract #F33615-92-C-0018. This final report (DIN A012) provides summaries of requirements and objectives from Section C (Description/Specifications) and accomplishments including citations and abstracts for the publications documenting results of specific efforts. The KLSI research team designed, performed, and/or provided support for experiments to support on-going RDT&E efforts in the following areas: the effect of physical conditioning on acceleration tolerance/endurance; female G tolerance/endurance; effect of varied periods of acceleration layoff on acceleration tolerance/endurance; effect of crewmember posture and position on acceleration tolerance/endurance; use of animal models for human acceleration tolerance/endurance; life support equipment development laboratory; testing of life support equipment, subatmospheric research; molecular sieve technology; spatial disorientation (SD) countermeasures research; sustained operations research; biomedical laboratory operation and support; and task order requirements.

The organization of this report follows the numerical sequence in Section C: Statement of Work, Part 3, Requirements. Task Orders are enumerated under 26, Task Order Requirements. In cases where the accomplishments require additional discussion, it is included in the appropriate section. Reports which were not published in the literature have been presented to the Crew Technology Division Technical Monitor for inclusion in the contract file.

The Author cross-reference allows the reader to find the portion of this report which contains abstracts of published works any KLSI author. The Bibliography of all published abstracts/articles under this contract includes an additional [bracketed] cross-reference to the numbered requirement (e.g. [26.20] refers to Task Order Requirements, Task Order 20).

KRUG LIFE SCIENCES INC. PERSONNEL AND CROSS-REFERENCE

The KLSI contract support personnel and authors cited throughout this report are listed here in alphabetical order with their calendar years of KLSI employment, cross-referenced to the section of the report under which they provided support. The underlined sections contain published abstracts with the KLSI contractor as an author.

KLSI Contractor	CY of Support	Section
Alexander, Heather O.	1991-1997	11
Barber, Judith A.	1988-1997	1, 8, 15.1
Beene, Donya K.	1993-1997	11, 26.6, 26.8, 26.10, 26.20
Cagle, Marianna P.	1993-1997	15.2
Calloway, James A.	1995-1996	26.16
Cato, Matthew J.	1992-1997	15.2, 26.11
Coffey, Douglas J.	1984-1992	1
Cottrell, Stephanie K.	1995-1997	1
Curtis, Laurie C.	1993-1997	26.7, 26.12, 26.16
Dillon, Nathan A.	1995-1997	26.14
Ercoline, William R.	1989-1996	1, 13
Echon, Roger M.	1992-1997	8, 15.1
Elizondo, Victor D.	1997	26.22
Fischer, Christy L.	1993-1996	1
Fischer, Michele D.	1990-1997	2, 3, 5, 11, 14, 26.8
Fisher, Janet L.	1993-1994	1
Freeman, David F.	1990-1995	26.2, 26.14
Galindo, Samuel Jr.	1991-1997	2, 3, 8, 15.1
Gannon, Robert L.	1994-1995	26.11
Hade, Edward W.	1993-1997	26.2, 26.10, 26.22
Harless, Yolanda C.	1990-1993	1
Heaps, Christine L.	1990-1995	1, 5, 11
Hearon, Christopher M.	1995-1997	1, 2, 3, 5, 11, 14
Hill, James	1997	26.19
Holden, Ronald D.	1993-1997	26.10, 26.14
Jones, Donna M.	1991-1997	9, 26.1
Krause, Kevin M.	1996-1997	11, 26.20
Krutz, Robert W. Jr.	1982-1996	1, 4
Lessard, Charles S.	1996-1997	1, 13
Magaw, Daniel M.	1995-1997	26.16, 16.17
Matthews, Danny L.	1990-1993	9
McLean, Sean D.*	1989-1991	26.8
Melkonian, Amie D.*	1989-1990	11
Michel, Anna Marie	1993-1997	1, 15.2, 26.11
Miller, George W.	1993-1997	1, 12, 26.9, 26.14

Ohlhausen, John H.	1989-1997	1, 10, 12, 26.9, 26.14
Olson, Robert M.	1983-1995	11, 26.8
Perez, Ricardo III	1993-1997	9
Petropoulos, Lambros P.	1993-1997	11
Rabinowitz, David M.	1993-1997	1, 26.13, 26.19
Regnault, Heather M.	1997	15
Ripley, Edward P.*	1991	11
Ripley, Grady L.	1990-1994	4, 5, 10
Robinson, Jemett L.	1989-1997	8
Schaper, Daniel O.	1997	15
Scott, Paul A.	1995-1996	26.21
Shaffstall, Robert M.	1993-1997	26.3, 26.4, 26.12, 26.16, 26.18
Shahed, Asha R.**	1995-1997	15.1
Shakocius, Aaron M.	1989-1997	12
Sipes, Walter E.	1994-1997	1, 13
Smith, Brian T.	1995-1997	26.14
Stegmann, Barbara J.*	1990-1991	4
Stiles, Carolyn S.	1982-1996	26.10
Webb, James T.	1987-1997	1, 2, 4, 11, 14, 26.10, 26.20
Weinstein, Lisa F.	1991-1994	13
Wiegman, Janet F.	1989-1992	5, 8, 11, 26.8
Yarbrough, Shawn R.	1995-1997	13
Zhou, Yi	1996-1997	26.18

* Worked on previous contract; papers published during current contract

** Subcontractor author

LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

A/A	Air-to-Air
AAOM	Advanced Aircrew Oxygen Mask
ADRAC	Altitude Decompression sickness Risk Assessment Computer
AEWPL	Applied Exercise and Work Physiology Laboratory
AFRL	Air Force Research Laboratory (Formerly Armstrong Laboratory)
A/G	Air-to-Ground
AGSM	Anti-G Straining Maneuver
AHOS	Advanced Hybrid Oxygen System
AHOS-M	Advanced Hybrid Oxygen System-Medical
ASDD	Advanced Spatial Disorientation Demonstrator
AL	Armstrong Laboratory (formerly USAFSAM)
AOI	Acoustic Orientation Instrument
APSO	Acceleration Protective System Optimization
ATAGS	Advanced Technology Anti-G Suit
CBF	Cerebral Blood Flow
CBS	Computerized Breathing Simulator
CBV	Cerebral Blood Volume
CFM	Cubic Feet per Minute
COMBAT EDGE	COMBined Advanced Technical Enhanced Design G Ensemble
CT	Circadian Times
DCS	Decompression Sickness
DFDR	Digital Flight Data Recorder
DIN	Data Item Number
EEG	Electroencephalography
EVA	Extravehicular Activity
FAA	Federal Aviation Administration
FATE	Female Acceleration Tolerance Enhancement
FDA	Food and Drug Administration

FSWG	Flight Symbology Working Group
G	Gravitoinertial force
G-LOC	G-Induced Loss of Consciousness
GOR	Gradual Onset Run
HDD	Head-Down Display
HMD	Helmet-Mounted Display
HM-ESS	Helmet-Mounted Electrophysiology Sensing System
HPLC	High Performance Liquid Chromatography system
HPMSOC	High Performance Molecular Sieve Oxygen Concentrator
HTML	Hypertext Mark-up Language
HUD	Head-Up Display
ILS	Instrument Landing Systems
KLSI	KRUG Life Sciences Inc.
LAN	Local Area Network
LBNP	Lower Negative Body Pressure
LEPD	Laser Eye Protection Device
LSA	Loss of Situational Awareness
LSE	Life Support Equipment
LSETL	Life Support Equipment Testing Laboratory
LSEDL	Life Support Equipment Development Laboratory
MSOC	Molecular Sieve Oxygen Concentrator
MSOGS	Molecular Sieve Oxygen Generating Systems
NVG	Night Vision Goggles
PAOT	Post Acceleration Onset Times
PAB	Performance Assessment Battery
PBG	Positive Pressure Breathing for G
PSA	Pressure Swing Adsorption
RAF	Royal Air Force
RDT&E	Research, Development, Test, and Evaluation
REAGS	ReEntry Advanced G Suits

RLV	Reuseable Launch Vehicle
SA	Situational Awareness
SAC	Small Animal Centrifuge
SCN	Suprachiasmatic Nuclei
SD	Spatial Disorientation
SGI	Somatogravic Illusion
SHARP EDGE	Sustained High Altitude Respiratory Protection Enhanced Design G Ensemble
SO	Spatial Orientation
SOAR	Space Operations and Applications Research
UA	Unusual Attitude
UPT	Undergraduate Pilot Training
USAF	United States Air Force
USN	United States Navy
VOL	Visual Orientation Laboratory
VGE	Venous Gas Emboli
VPBS	Variable Profile Breathing Simulator
WAT	Wingate Anaerobic Test
WST	Weapons System Trainer
WWW	World Wide Web

REQUIREMENTS

1. GENERAL

The contractor shall provide all necessary personnel and equipment other than Government Furnished Equipment (GFE) to accomplish the specific RDT&E, and support requirements at Brooks AFB, Texas. The contractor shall furnish a research team to design and perform experiments in support of RDT&E efforts. The contractor shall perform RDT&E task order requirements as issued by the Contracting Officer (CO).

Accomplishments

KLSI provided a team to provide research support of RDT&E efforts and task order requirements. Research reports (DIN A005, DIN A009, DIN A010, and/or DIN A016) completed under this effort which resulted from data gathered prior to contract start include:

Heaps CL, Coffey DJ, Constable SH. Effect of rate of heat gain while at rest on selected serum enzymes in rhesus monkeys. Med. Sci. Sports Exer. 1993;25 (Suppl):S29.

Abstract: "It has been demonstrated in rats that the rate of body heat storage (S) contributes to increased membrane permeability during the prodromal phase of heatstroke. The purpose of the present research was to document this effect in primates. On separate occasions, unacclimatized, female rhesus monkeys (N=6) were exposed to two different environmental heat loads while seated in a primate restraint chair. The two heat loads, 50 C, pH2O>50 torr (high stress; HS) vs. 45 C, pH2O<10 torr (low stress; LS), resulted in dissimilar rates of body heat storage. Heat exposure was terminated when core temperature (Tre) reached a pre-selected endpoint of 41.0 C. Serum levels of creatine phosphokinase (CPK), lactate dehydrogenase (LDH), aspartate aminotransferase (AST) and alanine aminotransferase (ALT) were determined immediately post-exposure (control) and at 6 h and 24 h following termination of the exposure. Body weight, blood lactate (La), hemoglobin and hematocrit were also determined at each of these time points. Total exposure time (mean + SE) differed significantly between trials (HS = 38 + 2; LS = 81 + 9 min). Because absolute increase in Tre was similar in both the HS and LS trials (2.20 + 0.1 vs. 2.23 + 0.1 C, respectively), the rate of heat gain was significantly greater during the HS vs. the LS trial. There were no differences in any of the marker enzyme responses between the HS and LS groups. LDH and AST levels rose modestly over time from pooled control levels (171 + 10 and 21 + 1 IU/L) during both the HS and LS trials to 24 h levels (265 + 37 and 35 + 5 IU/L), respectively. However, CPK, ALT and La were not significantly elevated across time in either trial. The HS condition allowed for little, if any, evaporative heat loss (0.08 + 0.05 vs. 0.51+ 0.05 g.min-1; HS vs. LS). Blood volume increased similarly in both the HS (+4.5 %) and LS (+5.5 %) trials. These findings indicate that acute heat exposure, at these levels of S, does not appear to provide an adequate thermal stress in rhesus monkeys for meaningful elevations of the serum enzymes, indicative of increased tissue permeability. (AFOSR Grant #92AL018)"

Heaps CL, Constable SH. Physiological responses of rhesus monkeys to exercise at varied temperatures. Aviat. Space Environ. Med. 1995;66:137-42.

Abstract: "This research characterizes the effects of selected physiological stressors such as work and various environmental heat loads on rhesus monkeys. Non-human primates were behaviorally conditioned to exercise in a wheel ergometer at approx. 3 METs (1 MET = 3.5 ml O2uptake per kg per min). On separate days, each monkey attempted six work/rest cycles. Core temperature (Tco), body weight (BW) and blood samples were taken immediately before and after exercise. Excessively high heat storage rates dictated that the 35 C trial be limited to three work/rest bouts. The findings of this study indicate that the increased heat storage observed at higher environmental heat loads appears to substantially limit the amount of work these primates can perform, possibly the result of a limited sweat production capacity. Additionally, plasma glucose following exercise decreased to levels not typically seen in humans. The general metabolic profile in these primates was otherwise similar to that observed in humans at this work level."

Heaps CL, Constable SH. Effect of rate of heat gain on selected serum enzymes in rhesus monkeys. AL/CF-TR-1993-0121. 1994;12pp.

Abstract: "Cell membrane leakage of sodium and potassium ions results in an energy drain at the cellular level as active transport activity must increase to maintain the membrane potential. This membrane permeability increases as body temperature rises, a result of an increase in the kinetic energy of the ions. Thermal stress and the resultant increased cell membrane permeability poses a challenge to the cell to maintain homeostasis and may contribute to fatigue during physical exertion. Ultimately, the work capacity of an individual may be limited by this cellular energy drain. Hubbard suggests that the rate of heat gain plays a significant role in the energy drain at the cellular level as membrane permeability increases dramatically with faster rates of heat storage. This relationship is described as part of the Energy Depletion Model developed by Hubbard et al. (4) and has been examined in the rat model by both Hubbard et al. and Manjoo et al."

Heaps CL, Constable SH. The metabolic and thermoregulatory responses of rhesus monkeys to combined exercise and environmental heat load. AL-TP-1993-0008. 1993;30pp.

Abstract: "The purpose of the present research was to characterize the effects of selected physiological stressors such as work and various environmental heat loads in rhesus monkeys. Nonhuman primates (N=6) were behaviorally conditioned to exercise in a wheel ergometer at approximately 3 METs. On separate days, each monkey attempted six work/rest cycles (10 min work:1 min rest) at 15, 25 and 35 C drybulb temperature, vapor pressure < 10 mmHg. Core temperature (Tco), body weight (BW) and blood samples were taken immediately before and after exercise. Excessively high heat storage rates dictated that the 35 C trial be limited to three work/rest bouts. Sweat rate (as determined by the change in BW over time) and the change in Tco during exercise were significantly greater during the 35 C trial as compared to the 15 and 25 C trials. Glucose levels (mean + SE) declined significantly during exercise from 4.35 + 0.1 and4.58 + 0.4 mM to surprisingly low levels of 1.67 + 0.2 and 1.76 +0.2 mM in the 15 and 25 C trials, respectively. Increases in blood lactate, glycerol and triglycerides were observed independent of environmental temperature. Free fatty acids increased during exercise in the 15

and 25 C trials but declined slightly during the shorter 35 C trial. The findings of this study indicate that the increased heat storage observed at higher environmental heat loads appears to substantially limit the amount of work these primates can perform, possibly the result of a limited sweat production capacity. Additionally, plasma glucose following exercise decreased to levels not typically seen in humans. The general metabolic profile in these primates was otherwise similar to that observed in humans at this work level."

Heaps CL, Gonzalez-Alonso J, Coyle EF. Hypohydration causes cardiovascular drift without reducing blood volume. Int. J. Sports Med. 1994;15:74-9.

Abstract: "To determine the effect of hydration on cardiovascular drift (i.e.; increased heart rate and reduced stroke volume) during exercise in a 21 degree C environment, 9 subjects were studied while cycling at 65% of peak oxygen consumption when euhydrated and while still hypohydrate, following exercise-induced dehydration and a 2h rest/rehydration period. Subjects dehydrated by exercising in the heat (32 C) until body weight was reduced 2.5%. On two separate occasions following exercise, subjects either received no fluid or ingested a volume of water equal to 100% of the fluid lost during exercise. Following the 2 h rest/rehydration period, 65+6% of the ingested water was retained and thus the subjects were hypohydrated by0.9+0.1%, compared to being hypohydrated by 2.8+0.1% when no fluid was ingested. Despite these differences in whole body hydration, blood volume during exercise remained at euhydrated levels when hypohydrated by 0.9% and 2.8%. However, the degree of cardiovascular drift was graded in proportion to hypohydration. Compared to the responses when euhydrated, heart rate was elevated 10+2 and 18+2 bt/min, whereas stroke volume was reduced 9+3 and 18+2 ml/bt, respectively, when hypohydrated by 0.9% and 2.8% during the water and no fluid trials ($p<0.05$ for all comparisons). These observations indicate that cardiovascular drift during exercise in a 21 C environment is graded in proportion to hydration and, under these conditions, not due to reductions in blood volume."

Krutz RW Jr., Webb JT. Aircrew/groundcrew life support systems research. Volume 1: CLIN 0001 research requirements. AL-TR-1993-0012-VOL-1. 1993;58pp.

Abstract: "USAF Contract #F33615-89-C-0603 (SOW Section 3.2; CLIN 0001) with KRUG Life Sciences, Incorporated, San Antonio Division, supported the Armstrong Laboratory by providing for research in the following areas: human research subjects, experimental life support equipment development laboratory, anti-G suit research, development, test, and evaluation (RDT&E), research databases, subatmospheric research, molecular sieve technology, centrifuge testing of life support equipment, centrifuge support, cockpit integration and crew performance, and spatial disorientation research. This final report provides summaries of objectives and accomplishments including citations and abstracts for the publications documenting the work.AL-TR-1993-0012-VOL-2 is the final report for the CLIN 0002 portion of this contract."

Webb JT, Krutz RW Jr. Aircrew/groundcrew life support systems research. Volume 2: CLIN 0002 task order requirements. AL-TR-1993-0012-VOL-2. 1993;48pp.

Abstract: "USAF Contract F33615-89-C-0603 (SOW Section 3.3; CLIN 0002) with KRUG Life Sciences, Incorporated, San Antonio Division, supported the Armstrong Laboratory by providing for research in the form of professional and technical personnel, resources, and when required, facilities necessary to accomplish task orders for research, development, test, and evaluation (RDT&E) to include, but not be limited to, the following topics: Chemical defense, experimental aeromedical and casualty care equipment laboratory support, biochemical laboratory support, test studies and evaluations, system integration/equipment modification, equipment design package, independent engineering tests, equipment fabrication, design and development, computer programs, specialized and unique R&D laboratory facilities, and altitude research. This final report provides summaries of objectives and accomplishments including citations and abstracts for the publications documenting the work. AL-TR-1993-0012-VOL-1is the final report for the CLIN 0001 portion of this contract."

2. HUMAN RESEARCH SUBJECTS

The contractor shall acquire and manage human volunteer subjects as required for research studies. The human subjects are required to be 18-50 years of age, high school graduates, and meet military height and weight standards. The subjects shall satisfactorily meet all requirements of the Armstrong Laboratory (AL) Test Subject Physical and any other physical or medical examinations or requirements specified by the approved protocol in which they are intended to participate. The contractor shall ensure that the human research subjects meet these medical requirements and are properly trained as required by each Government approved research protocol. Medical examinations required for contractor furnished research subjects will be accomplished by the AF at the USAF CLINIC BROOKS (AFSC). The contractor shall acquire personal liability insurance for the human research subjects as required by current Air Force directives from the Air Force Surgeon General. Minimum personal liability required shall be one million dollars for each human research subject for each incident.

Accomplishments

Subatmospheric Research. One hundred thirty-six (136) non-smoking (for preceding 2 years), military or contractor-acquired subjects between the age of 18 and 50 years of age participated in nine decompression sickness (DCS) protocols resulting in 799 exposures. Some exposures were preceded by ground-level exercise and performance training and, in several protocols, maximum oxygen uptake testing using dual-cycle ergometry exercise (see Section 11). All subjects passed the appropriate subject physical, and were otherwise representative of the USAF rated aircrew population. The voluntary, fully-informed consent of the subjects used in this research was obtained in accordance with AFI 40-402. They were not required to meet flying standards and were rejected only for evidence of conditions which might abnormally impair their tolerance to altitude or exercise. They were tested and shown to be HIV negative. Female subjects had a negative pregnancy test within 36-72 hours prior to each altitude exposure depending on

Armstrong Laboratory Advisory Committee for Human Experimentation guidelines in existence at the time. KLSI was involved in recruiting, initial briefing/screening, medical exam scheduling, and specific protocol briefing of these subjects. KLSI personnel accomplished most of the laboratory notebook maintenance (DIN A004) and computer data entry (DIN A007). KLSI conducted all exercise training and testing, exposure scheduling, and contractor subject records maintenance during the contract period.

Scientific and technical support was provided for the protocol "Decompression training at or below 10,000 feet using 100% oxygen without prebreathe" (under Altitude Generic Protocol). This protocol was designed to prepare new subjects for research chamber procedures and operations and to familiarize them with the research chamber equipment. Eighty-eight subjects were trained under this protocol.

Acceleration Research. Twenty civilian contract human subjects were recruited for the Brooks AFB Acceleration Research Subject Panel. The type of subjects recruited were dependent upon the specific demands of the protocols for which the recruitment effort was undertaken. In general, all subjects will were required to fall within USAF guidelines with regards to age, weight, height and body composition. Other specifics such as gender, physical fitness level, smoking status, etc. were incorporated into the recruitment profile based on specific protocol demands. The majority of the recruitment took place on local university/ college campuses or fire/police departments where advertisements were placed in campus/department newspapers/bulletins requesting volunteers for certain studies. Mass briefings were given at these sites (arranged through the AFROTC at the colleges if possible) to inform the potential subjects of the requirements/demands/risks of the protocols for which they were being recruited. At this time, a general health history screening of the potential subjects was conducted to eliminate those individuals who have known health conditions/histories which would preclude their participation as a research subject. Those individuals still interested in becoming subjects and who had passed the general health history screening, were brought to Brooks AFB for a military briefing of the research protocol(s) of interest by the Principal Investigator and Operations Chief/personnel as well as a tour of the facilities. Individuals still interested were sent to KLSI for processing to become employees (i.e., drug screening, clerical work, etc.). Upon becoming a part-time employee at a negotiated wage rate, the subjects began the USAF medical clearance process as defined by the SGO and performed by the FSO (70th Medical Squadron, Brooks AFB). Upon FSO approval, the subjects became full members of the research subject panel. KLSI. was responsible for maintaining all records, pay scales/time sheets and insurance for all of these subjects until their removal from the subject panel. Specific protocols for which subjects were recruited include: 1) "Comparison of Male And Female Acceleration Tolerance During +5-9 G_z Simulated Aerial Combat Maneuvers" (AL ACHE #93-05E) 2) "Female +G_z Protective Equipment Fit and Male/Female +G_z Tolerance Comparison" (AL ACHE #94-27D) and 3) "Comparative Effects of Dynamic and Static Strength Training on +G_z Tolerance" (AL ACHE #96-08C).

3. *THE EFFECT OF PHYSICAL CONDITIONING ON ACCELERATION TOLERANCE/ENDURANCE*

The contractor shall recommend, design and conduct experiments to measure the effect of chronic and acute exercise on sustained acceleration tolerance/endurance and on performance of the Anti-G Straining Maneuver. The contractor shall recommend a conditioning program suitable for tactical aircrew members. The contractor shall record data on the aerobic and anaerobic condition of human subjects participating in acceleration experiments conducted by the Government. (DIN A003, A011)

Accomplishments

Presentation of research results and concept was provided as detailed below. Additionally, research protocols (data collection ongoing) were developed and AL/ACHE and SGO approval sought and secured for them and their subsequent revisions. These protocols are listed below. Support was also provided in the development, direction, operation and maintenance of the Applied Exercise & Work Physiology Laboratory (AL/CFT) and the Applied Exercise & Work Physiology Laboratory Annex (AL/CFT) and the equipment held therein. This included staffing of the laboratory with an Exercise Physiologist (Laboratory Director) and laboratory technicians (2). In addition to the research protocols originating from this laboratory, support was provided division wide for all protocols requiring exercise/work physiological testing, prescription and consultation and these protocols are listed below. Additionally, exercise/work physiology consultation was provided to other AF divisions and outside agencies as requested by AL/CFT.

Research reported (DIN A005, DIN A009, DIN A010, and/or DIN A016) from this effort includes:

Hearon CM, Fischer MD, Dooley JW. Relative anaerobic power estimated from the Wingate Test and endurance to high $+G_z$ centrifuge exposure (Abstract) Med. Sci. Sports Exerc. 1998;30(5 Suppl.):[In Press].

Abstract: "It has been suggested that one of the limiting factors to high $+G_z$ endurance is muscular strength. Previously, a significant relationship was reported between absolute anaerobic power (estimated from the Wingate Cycle Test (WCT)) and $+G_z$ endurance. This association was used in support of the relationship between muscular strength and $+G_z$ endurance. However, the relationship between power, relative to body mass, and $+G_z$ endurance was not significant. The study examined, on an all male sample, subject endurance to a relatively low $+G_z$ (4.5 to 7 G_z) simulated air combat maneuver (4.5-7 SACM) and used a WCT workload not in agreement with the most recent literature. In another study, similar results were shown on a sample of females exposed to the 4.5-7 SACM, but again no significance was detected when the WCT data were analyzed relative to subject body mass. The present study examined the relationship between endurance to a high $+G_z$ (5 to 9 G_z) profile (5-9 SACM) and anaerobic power (estimated by WCT) relative to body mass. Subjects (6 females, 8 males) endured a 5-9 SACM to fatigue. All subjects utilized the anti-G straining maneuver and a "best-fit" anti-G suit to endure the centrifuge exposure. SACM duration (s) was recorded. Subjects performed the WCT according to the

most current published recommendations. In the sample examined, no significant relationship was found to exist between SACM endurance and either relative mean anaerobic power ($r=0.27$, $p=0.3488$) or relative peak anaerobic power ($r=0.09$, $p=0.7625$). The data clearly suggest that anaerobic power (estimated from the most current WCT procedures) reported relative to body mass (as recommended by WCT literature when examining subjects varying in body mass) is not significantly related to 5-9 SACM endurance. However, these results do not question the findings of previous studies which suggest that muscular strength is a limiting factor to high $+G_z$ endurance. The data obtained from the WCT reflect muscle power and local muscle endurance and not specific muscular strength. While, in theory, the WCT variables should correlate with muscular strength, a battery of specific strength tests should be utilized to better define the role of muscular strength in $+G_z$ performance."

Protocols written/approved with data collection ongoing: 1) "Comparative effects of dynamic and static strength training on $+G_z$ Tolerance" (AL ACHE #96-08C); 2) "The effect of short duration respiratory musculature training on Tactical Air Combat Maneuver Endurance and Recovery" (AL ACHE #96-27B); and 3) "Effects of supplemental dietary creatine monohydrate on positive G_z-tolerance/endurance in males and females" (AL ACHE #97-39)

Additional protocols supported: 1) "Validation of the Operation of the Sensormedics 2900z Metabolic Cart and Metabolic Gas Exchange During" $+G_z$ (AL ACHE #96-16); 2) "Effect of Assisted Positive Pressure Breathing on the Incidence of Acceleration Atelectasis While Breathing 100% Oxygen During $+G_z$" (AL ACHE #95-23); 3) "Effect of Exercise on Altitude Decompression Sickness" (AL ACHE #91-07); 4) "Effect of Exercise with 100% Oxygen while Exercising on Incidence of Decompression Sickness" (DCS) (AL ACHE #89-25B); and 5) "Preoxygenation with Exercise Versus Rest: Effect on Incidence of Decompression Sickness (DCS)" (AL ACHE #94-17A).

4. ACCELERATION PROTECTIVE SYSTEMS RDT&E

The contractor shall perform RDT&E, design, and fabrication to improve the acceleration tolerance/endurance of tactical aircrew members. The contractor shall address improvements of the Advanced Technology Anti-G Suit (ATAGS) and the COMBAT EDGE ensemble. The contractor shall include modifying the ATAGS abdominal bladder for performance and comfort; determining the effectiveness of pressure applied to the arms; optimization of the pressure schedule in both ATAGS and COMBAT EDGE; optimization of the integration of the counterpressure garment of COMBAT EDGE and ATAGS; optimization of the human factors engineering of the COMBAT EDGE garment and the ATAGS; use of an improved breathing regulator/anti-G (BRAG) valve; and the effectiveness of ATAGS cooling. The contractor shall develop and manufacture experimental equipment for the Life Support Equipment Laboratory. (DIN A003, A011)

Accomplishments

Research reports (DIN A005, DIN A009, DIN A010, and/or DIN A016) from this effort include:

Besch EL, Werchan PM, Wiegmen JF, Nesthus TE, Shahed AR. Effect of hypoxia and hyperoxia on human $+G_z$ duration tolerance. J. Appl. Physiol. 1994;76:1693-1700.

Abstract: "To determine the effects of varying inspired O2 on positive radial acceleration ($+G_z$; i.e., head-to-foot inertial load) duration tolerance, seven men were exposed to the +4.5 to 7.0 G_z simulated aerial combat maneuver (SACM) by use of the Armstrong Laboratory (Brooks Air Force Base) centrifuge. Exposures were repeated on different days while subjects breathed gas mixtures of fractional concentration of O2 inspired air (FIo2) between 0.12 and 0.6. SACM duration tolerance was positively related to inspired O2 of FIo2 between 0.12 and 0.2 but was unchanged at FIo2 between 0.2 and 0.6. SACM exposure decreased arterial O2 saturation and increased heart rates; SACM-induced changes were additive to FIo2 effects. The positive relationship between blood lactate and SACM duration tolerance at all FIo2 indicated an anaerobic component. It is concluded that SACM duration tolerance is limited by reduced FIo2 but not enhanced by hyperoxia. Thus the aerobic component of +4.5 to $+7.0G_z$ SACM duration tolerance is much greater than previously believed."

Forster EM, Barber JA, Parker FR Jr, Whinnery JE, Burton RR, Boll P. Effect of pyridostigmine bromide on acceleration tolerance and performance. Aviat. Space Environ. Med. 1994;65:110-6.

Abstract: "Pyridostigmine Bromide (PB) is used as a pre-exposure antidote for the prevention of potentially lethal effects of certain chemical warfare nerve agents by reversibly inhibiting acetylcholinesterase (AChE). This study was designed to determine whether PB has any deleterious effects on acceleration tolerance ($+G_z$) or performance. Double-blind placebo trials were conducted to evaluate the effects of PB (90 mg) per day on $+G_z$ tolerances and performance. Three types of exposures were used: 1) gradual onset rate (GOR) exposures of 0.1 G/s; 2) a series of rapid onset rate (ROR) exposures of 6.0 G/s; and 3) a simulated aerial combat maneuver (SACM) of 4.5 to 9.0 $+G_z$. Performance tasks included the Unified Tri-Service Cognitive Performance Assessment Battery (UTC-PAB). The subjects were not able to correlate their symptoms with PB, placebo, or the acceleration exposure itself. Plasma PB individual levels ranged between 6 and 31 ng/ml and AChE levels of inhibition had a range of 12 to 45%. There were no significant effects o $+G_z$ tolerance or performance. Therefore, we do not expect aircrew taking prophylactic doses of PB to be adversely affected during aerial combat operations."

Krutz RW Jr., Sawin CF, Stegmann BJ, Burton RR. Preinflation before acceleration on tolerance to simulated space shuttle reentry G profiles in dehydrated subjects. J. Clin. Pharmacol. 1994;34:480-83.

Abstract: "This study was conducted to determine if preinflation of a standard five-bladder anti-G suit 10 minutes before exposure to a centrifuge simulation of a Space Shuttle reentry would provide significantly better protection against orthostasis than the standard symptomatic inflation

regimen. This study differed significantly from prior studies: The rate of G onset was slower, peak G was lower, duration of exposure was longer, and the subjects were dehydrated to mimic conditions observed in astronauts immediately postflight. Preinflation demonstrated physiological advantages as determined by arterial blood pressure and heart rate changes in seven healthy male, experienced centrifuge subjects."

Ripley GL, Solana KE, Hill RC. Female anti-G suit fit and comfort. SAFE J. 1994:24:41-5.

Abstract: "A survey was completed to: a) to obtain data to describe fit, comfort and effectiveness of anti–G suits worn by AETC aircrew; and b) determine modifications performed by individual units. The subject population was male and female T–38 instructor pilots (IPs), students currently undergoing pilot training in the T–38, and T–37IPs with T–38 experience. Seven female centrifuge subjects wearing the CSU-13B/P anti–G suit were also questioned. The survey to date showed that 50% of the women believed their anti–G suit loose in the waist, while 27% of the men had the same problem. Discomfort, specifically of the abdomen with bladder inflation was reported in 32% of males and 14% of females. However, all of the female centrifuge subjects complained that the abdominal bladder compressed their ribs and made breathing difficult. Alterations, primarily reducing abdominal bladder circumference were made to anti–G suits for 29% of the females pilots and 9% of the male pilots. Females may experience greater difficulty in achieving a good anti–Gsuit fit. Although this is not a problem in operations of the T-38 environment (e.g., +7 G_z maximum), higher G levels of aerial combat present a greater challenge."

Tong A, Hill RC, Tripp L, Webb JT. The effect of head and body position on +G_z acceleration tolerance. Aviat. Space Environ. Med. 1994;65(4, Suppl):A90-4.

Abstract: "It has been suggested there is a relationship between acceleration-induced loss of consciousness (G-LOC) and head/body position. A two-part investigation was conducted to determine whether head and body position affects acceleration tolerance. A retrospective analysis of high-G training data (N = 1,914) compared G-LOC occurrence during straight-ahead exposure to a "check-6" exposure [10 s at +9 G_z; 6 G/s onset rate; G-suit inflated; anti-G straining maneuver (AGSM) performed]. A prospective study (N = 12) was conducted with acceleration exposures using light loss criteria with subjects in straight-ahead, above, over-the-right shoulder, or over-the-left shoulder positions. Profiles consisted of 0.1 G/s onset-rate runs (no G-suit inflation; relaxed) to a maximum of +9 G_z and 0.5 G/s onset-rate runs (G-suit inflated; AGSM performed) to +9 G_z for up to 26 s. In the retrospective study, no significant difference existed in the time at maximum G among any of the positions. During the relaxed runs, several comparisons yielded significant differences in peak G attained. These results indicate there may be an underlying physiologic effect of head and body position on acceleration tolerance; however, the AGSM and the G-suit overcame this effect. Although task saturation and distraction may compromise performance of the AGSM and subsequently predispose acceleration-related hazards, a proper AGSM, combined with effective protective systems, remains essential components of a protection strategy."

5. FEMALE G TOLERANCE/ENDURANCE

The contractor shall recommend, design and conduct studies to determine the responses of females to high onset and sustained $+G_z$ acceleration. The contractor shall compare the data to male $+G_z$ tolerance and endurance. The contractor shall study differences, if found, to determine possible causes, e.g., physical strength, anaerobic or aerobic capacity, anthropometrics, or the fit or design of anti-G equipment. If existing anti-G equipment is found to be inadequate for female subjects, the contractor shall design, fabricate and test new equipment for females. The contractor shall review existing USAF physical standards and recommended exercises for increasing $+G_z$ tolerance for males and determine if and how these shall be modified for females. (DIN A003, A011)

Accomplishments

Presentation of research results and concept were provided as detailed below. Additionally, research protocols (data collection ongoing) were developed and AL/ACHE and SGO approval sought and secured for them and their subsequent revisions. Research reported (DIN A005, DIN A009, DIN A010, and/or DIN A016) from multiple protocols under this effort include:

Dooley JW, Hearon CM, Shaffstall RM. The USAF female acceleration tolerance enhancement (FATE) project: Year III (Abstract). Aviat. Space Environ. Med. 1997; 68:624.

Abstract: "For the past three years, investigators of the Armstrong Laboratory (AL) Centrifuge at Brooks AFB, TX, have studied $+G_z$ tolerance and simulated aerial combat maneuver (SACM) endurance of female acceleration panel subjects, relative to standard and advanced $+G_z$-protective equipment and the level of selected physical fitness parameters. The Female Acceleration Tolerance Enhancement (FATE) Project was a USAF response to the 1993 U.S. Secretary of Defense directive to open combat aircraft assignments to women. Accomplishments include: (1) design and fabrication of an extra small, short standard anti-G suit (CSU-13B/P) to accommodate the smaller aircrew authorizations for JPATS and future high performance aircraft; (2) acceptance of a "best fit" AL modification of the standard anti-G suit for females as a Safety Supplement to the CSU-13B/P Technical Order; (3) completion of a +5 to $+9G_z$ SACM study comparing male and female tolerance/endurance in the CSU-13B/P; and (4) a second male/female comparative study using a new Tactical Aerial Combat Maneuver (TACM) centrifuge profile to evaluate AL modifications and new sizing schemes for advanced USAF $+G_z$-protective equipment (COMBAT EDGE and ATAGS). Data will be presented on the comparative analyses of $+G_z$ tolerance/endurance in males and females wearing CSU-13B/P and advanced $+G_z$-protective equipment ensembles as well as the relationship of physical fitness parameters to $+G_z$ tolerance/endurance."

Solana KE, Ripley GL, Hill RC. Female anti-G suit fit and comfort. (Abstract) Aviat. Space Environ. Med. 1993;64:450.

Abstract: "INTRODUCTION. Sizing for the CSU-13B/P anti-G suit, used by the USAF, was designed based on male height, weight, and body circumference. Variances between male and

female body proportions lead to the question of the degree of protection provided to females during G stress. According to a 1967 survey USAF flying personnel, 93% of males met height/weight criteria for sizing the CSU-13BP anti-G suit. A 1968 survey of USAF women established 59% of females, 162.6 cm and above, met height/weight guidelines for sizing of theCSU-13 B/P. We are completing a survey to: 1) obtain data to describe fit, comfort and effectiveness of anti-G suits worn be ATC aircrew; and b) determine modifications performed by individual units. METHODS. The subject population was T-38 instructor pilots (IPs), T-37 IPs with T-38 experience, and students undergoing pilot training in the T-38. Seventy percent of the female IPs and student pilots from four ATC bases were surveyed. An equal number of male IPs and students was also sampled. Seven female centrifuge subjects wearing the CSU-13B/P anti-G suit were also questioned after participating in a study. RESULTS. The survey to date showed 50% of the women believed their anti-G suit was loose in the waist, while 27% of the men had the same problem. Abdominal discomfort was reported in 32% of males and 12.5% of females upon bladder inflation. All of the female centrifuge subjects complained the abdominal bladder compressed their ribs and made breathing difficult. Alterations were made to anti-G suits for 25% of females and 1% of males, most involved taking in the abdominal bladder circumference. CONCLUSION. Females may experience greater difficulty in achieving a good anti-G suit fit. Although this is unlikely to be a problem in the T-38 (e.g., +7 G_z maximum), the protection afforded to women at higher levels of acceleration could be compromised by poor anti-G suit fit."

Male And Female Acceleration Tolerance

Scientific monitoring and writing and technical support activities were provided for the protocol "Comparison of Male And Female Acceleration Tolerance During +5-9 G_z Simulated Aerial Combat Maneuvers" (AL ACHE #93-05E). Research reports (DIN A005, DIN A009, DIN A010, and/or DIN A016) from this effort include:

Hearon CM, Fischer MD, Dooley JW. Male/female SACM endurance comparison: Support for the AL modifications to the CSU-13B/P anti-G suit. (Abstract; manuscript in review) Aviat. Space Environ. Med. 1997;68:656.

Abstract: "INTRODUCTION. The standard anti-G suit was designed on the basis of male body structure. Females differ from males with respect to body proportionality adjusted for body mass/stature. These suits' effectiveness for females has been questioned. In Armstrong Laboratory (AL) centrifuge studies, females have terminated centrifuge simulated air combat maneuvers (SACM) due to anti-G suit discomfort (CSU-13B/P modified according to T.O. 14P3-6-121)(TO suit). AL modifications (ALM suit) to the suit have since been adopted in the TO in an attempt to provide subjects, specifically females, a best-fit suit. The purpose of the study was to examine SACM endurance between males and females, with the females wearing both the TO and the ALM suits. METHODS. 5 females and 8 males were exposed to a +5 to +9 G_z SACM (5-9 SACM) to fatigue following a series of gradual- and rapid-onset acceleration profiles. During the SACM profile, subjects used the anti-G straining maneuver with anti-G suit inflation. SACM duration (mean ±SE in s) was recorded. The females performed duplicate data runs in both the TO and ALM suits while the males performed duplicate runs in the TO suit only (i.e., the TO was their best-fit suit). RESULTS. When comparing the males and females in the TO, the

males were able to perform the SACM significantly ($p>0.05$) longer (169.4 ± 19.1 s) than the females (101.4 ± 20.1 s) who all reported terminating exposures due to suit related discomfort. However, when the females performed the SACM in the ALM suit, their endurance almost doubled over their TO performance (202.4 ± 27.8 s) and no subject reported suit discomfort. While the females actually exhibited greater endurance than the males in their best-fit suit, the difference (202.4 ± 27.8 s vs 169.4 ± 19.1 s) was not significant ($p>0.05$). CONCLUSIONS. These data support the efficacy of the AL modifications to the CSU-13B/P anti-G suit through greatly improved performance during the 5-9SACM in females (i.e., those most likely to need the modification). These data also suggest that, in the sample examined, when fitted with a best-fit anti-G suit, females can endure the 5-9 SACM to the same degree as males."

Hearon CM, Fischer MD, Dooley JW. Male/female SACM endurance comparison: support for the Armstrong Laboratory modifications to the CSU-13B/P anti-G suit. Aviat. Space Environ. Med. 1997; manuscript in review.

Abstract: "BACKGROUND. The standard anti-G suit (CSU-13B/P) was designed based on male body structure. Females differ from males with respect to body proportionality. In Armstrong Laboratory (AL) studies, females have terminated centrifuge simulated air combat maneuvers (SACM) because of anti-G suit (CSU-13B/P modified according to original T.O. 14P3-6-121)(OTO) discomfort. AL modifications to the suit have since been adopted in the OTO in an attempt to provide females a best-fit suit (AL Mod). The study examined male/female SACM endurance with females wearing both the OTO and the AL Mod suits. METHODS. 6 females and 8 males performed a +5.0 to +9.0 G_z SACM to fatigue using the anti-G straining maneuver with anti-G suit inflation. The females performed in both the OTO and AL Mod suits, while the males performed in the OTO suit only (OTO was their best-fit suit). RESULTS. Wearing the OTO, males performed the SACM significantly longer than the females, three of whom reported severe suit discomfort. However, when the females wore the AL Mod suit, their SACM endurance almost doubled over their OTO performance and none reported suit discomfort. When wearing their best-fit suits, there was no significant gender difference in SACM. CONCLUSIONS. These data support the efficacy of the AL modifications to the CSU-13B/P anti-G suit through greatly improved performance during the +5.0 to +9.0 G_z SACM in females. These data also suggest that, in the small sample examined, when fitted with a best-fit anti-G suit, females can endure the +5.0 to +9.0 G_z SACM to the same degree as males."

Hearon CM, Fischer MD, Dooley JW. Relative anaerobic power estimated from the Wingate Test and endurance to high $+G_z$ centrifuge exposure (Abstract) Med. Sci. Sports Exerc. 1998;30(5 Suppl.):[In Press; see Section 3 for abstract].

Relative Effects of Physical Training State and Menstrual Cycle on the Female Physiologic Response to Sustained $+G_z$" (AL/ACHE 91-21)

Fischer MD, Heaps CL, Wiegman JF, Hill RC. Female $+G_z$ tolerance to the 4.5-7 simulated aerial combat maneuvers acceleration profile. (Abstract) Aviat. Space Environ. Med. 1993;64:450.

Abstract: "INTRODUCTION. While some data are available to describe female tolerance to acceleration levels > +7 G_z, there are no published data which describe female tolerance to sustained (>15 s) +G_z at these levels. Studies in high, sustained acceleration often use a simulated aerial combat maneuver (SACM) centrifuge profile that alternates 15 s plateaus of +4.5 and +7 G_z. The purpose of this study was to describe the +G_z-duration tolerance of females relative to male +G_z-duration tolerance and physical condition (i.e., strength, aerobic and anaerobic capacity). Data related to menstrual cycle and anti-G suit fit and effectiveness were also recorded. METHODS. Following high-G training, female subjects completed 8 SACM experimental sessions each (1x/wk for 2 complete menstrual cycles). During each session, subjects performed 3 centrifuge profiles: a relaxed gradual-onset run to light loss criteria without suit inflation; +5 G_z for 15 s with suit inflation; and the 4.5-7 SACM with suit inflation and anti-G straining maneuver (AGSM). Blood was sampled by finger-prick for lactate determination pre-G, pre-SACM, and 3 and 6 min following SACM. Subjects also completed tests for upper and lower body isometric strength, and aerobic (Bruce treadmill) and anaerobic (Wingate ergometer) capacity. RESULTS. The female subjects tested, thus far, exhibit less strength and anaerobic capacity than male counterparts. Limited data, collected to date, are insufficient to show a difference between male and female 4.5-7 SACM duration. Should similar durations be observed, despite differences in physical condition, this may be attributed to differences in anthropometrics. No menstrual cycle effects on SACM duration have been detected; however, training effects, the anti-G straining maneuver, and anti-G suit may have reduced the possibility of detection. CONCLUSION. Although females, in general, have less strength and anaerobic capacity than males, this may not adversely affect female +G_z tolerance to the 4.5-7 SACM."

Heaps CL, Fischer MD, Hill RC. Female acceleration tolerance: Effects of menstrual state and physical condition. Aviat. Space Environ. Med. 1997;68:525-30.

Abstract: "INTRODUCTION. The literature contains a paucity of information on female tolerance to high sustained acceleration. With women now flying high-performance aircraft, gender-specific factors that may affect female acceleration tolerance have become increasingly important. The purpose of this investigation was to determine how menstrual state and physical condition affect acceleration tolerance. We hypothesized the menstrual cycle would have no effect on acceleration tolerance and that a positive correlation would exist between physical fitness level and tolerance to high sustained acceleration. METHODS. Centrifuge exposures on 8 female subjects consisted of a relaxed gradual-onset run (0.1 G s^{-1}) to the visual endpoint, a rapid-onset run (6 G . s^{-1}) to +5 G_z for 15 s, and a +4.5 to +7 G_z simulated aerial combat maneuver (SACM) to physical exhaustion. Acceleration tolerance data were collected at onset of menstruation and 1, 2 and 3 weeks following the onset for two complete menstrual cycles. On separate days, body composition, anaerobic power output and peak oxygen uptake were determined. Retrospective data from 10 male subjects who had performed the +4.5 to + 7 G_z SACM were analyzed and compared to these data. RESULTS. Analysis of variance revealed no significant difference in relaxed tolerance or SACM duration between the four selected menstrual cycle time points. Time-to-fatigue on the +4.5 to +7 G_z SACM was positively ($p < or = 0.05$) correlated with absolute fat-free mass ($r = 0.87$) and anaerobic power production ($r = 0.76$) in female subjects. However, when these variables were adjusted for total body mass, the significant

correlations no longer existed. No correlation was found between SACM duration and absolute (L min^{-1}) nor relative (ml. kg s^{-1} min^{-1}) aerobic fitness. Time-to-fatigue during the SACM was not significantly different between male and female subjects (250 ±97 and 246 ±149 s, respectively)."

Exercise physiologist writing support activities were provided for the protocol "The Wingate Anaerobic Test as an Indicator of Capacity for Simulated Aerial Combat Maneuvers" (AL/ACHE #88-14) which was completed during a previous contract.

Accomplishments

Research reported (DIN A005, DIN A009, DIN A010, and/or DIN A016) from this effort includes:

Wiegman JF, Burton RR, Forster EM. The role of anaerobic power in human tolerance to simulated aerial combat maneuvers. Aviat. Space Environ. Med. 1995;66:938-42.

Abstract: "The relationships of anaerobic power, blood lactate levels, and selected anthropometric measurements to $+G_z$ tolerance were examined in 10 adult males. Upper and lower body anaerobic indices were determined by Wingate anaerobic tests (WT). Acceleration tolerance was measured as duration time for a simulated aerial combat maneuver (SACM) centrifuge profile with alternating 4.5 and 7 $+G_z$ 15-s plateaus until exhaustion. Group mean (± SD) for SACM duration was 250 ±97 s. Peak blood lactate concentration was 4.9 ±1.5 mmol/L and overall rating of perceived exertion was 7.4 ±2.1 using the Borg Category-Ratio Scale. Group mean for WT lower body 30-smean power (MP, index of anaerobic performance) was 620 ±128 W; peak power (PP, highest 5-s power output) was 851 ±169 W. Upper body MP and PP were 380 ±68 W and 497 ±81 W, respectively. SACM duration time was positively correlated with lower body MP and PP, upper body PP, various body circumferences, weight, fat-free body weight, and height; but did not correlate with WT power outputs relative to body weight, or with other SACM variables. Results suggest that anaerobic power is an important physiologic component in SACM tolerance."

Additional Protocol Written/Approved with data collection ongoing: "Female $+G_z$ Protective Equipment Fit and Male/Female $+G_z$ Tolerance Comparison" (AL ACHE #94-27D)

6. *EFFECT OF VARIED PERIODS OF ACCELERATION LAYOFF ON ACCELERATION TOLERANCE/ENDURANCE*

The contractor shall recommend, design and conduct experiments to determine the effect on acceleration tolerance/endurance of varied, extended periods of time between acceleration exposure (layoff). The contractor shall consider at least three periods of layoff including 7, 14, and 28 days. (DIN A003, A011)

Accomplishments

An "Effect of Lay-Off" study was conducted by USAF researchers. KLSI provided extensive support for this effort by conducting pre- and post-layoff aerobic and anaerobic testing, technical support in G-suit fitting, and physiologist support to monitor centrifuge exposures[1] (DIN A005).

7. EFFECT OF CREWMEMBER POSTURE AND POSITION ON ACCELERATION TOLERANCE/ENDURANCE

The contractor shall research, develop and evaluate a seat to increase acceleration tolerance/endurance while minimizing the adverse impact on crew integration with the cockpit. The contractor's effort shall be in cooperation with the Government's ongoing research to determine man' s upper limit of $+G_z$ (maximum of +12 G_z). (DIN A003, A011)

Accomplishments

The "12 G" study was conducted by a Government researcher. KLSI provided technical support to assist in records keeping and data compilation leading to presentation of results[2] (DIN A005).

8. USE OF ANIMAL MODELS FOR HUMAN ACCELERATION TOLERANCE/ENDURANCE

The contractor shall provide veterinary support necessary to conduct experiments in accordance with guidance outlined in AFR 169-2, as supplemented, using animal analogues of human performance and physiology during acceleration. The contractor shall insure support consists of expert animal instrumentation and preparation for acceleration experiments. (DIN A003, A011)

Accomplishments

Research reports (DIN A005, DIN A009, DIN A010, and/or DIN A016) from this effort include:

Burns JW, Fanton JW, Robinson JL. The influence of the AGSM, PBG, and anti-G suit inflation on thoracic hemodynamics during $+G_z$ in swine. J Grav. Physiol. 1994;1:P48-P51. No abstract available.

Burns JW, Robinson JL. Hemodynamics of graded water immersion (WI) in the baboon. (Abstract) Aviat. Space Environ. Med. 1997;68:657.

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[1] Morgan, TR, Hill, RC, Burns, JW, Vanderbeek, RD. Effect of two-week and four-week layoffs on tolerance to +Gz. Aviat. Space Environ. Med. 1995;66:470.

[2] Burns, JW. "Upper limits of +Gz protection" Aviat. Space Environ. Med. 1998;69:[In Press].

Abstract: "Introduction Fluid-filled anti-G suits depend upon external fluid counterpressure to maintain near-normal hemodynamic events become beneficial. Methods Seven anesthetized male baboons (avg. wt. = 27.2 kg.) were catheterized f or measurement of left ventricular pressure (LVP), right ventricular pressure (RVP), mean aortic pressure (MAP), central venous pressure (CVP), pulmonary artery pressure (PAP), cardiac output (CO), and esophageal pressure (AEP). Rectal temperature averaged 33.5 *C. The animals were seated in a restraint chair and control (Contr) data were collected, followed by 5 discrete steps of WI (bath temp. = 34*C): 1) knee; 2) hip; 3) diaphragm, ; 4) mid-chest; and 5) neck. Each level was maintained until hemodynamic stabilization (avg. = 6 min.)

WI	LVP		RVP		MAP	PAP		CVP	EP	CO	SV	HR
	EDP	Peak	EDP	Peak		Dias	Sys					
Contr	7	147	4	29	115	8	25	3	-1.5	2.6	27	96
Knee	7	145	5	29	117	8	26	4	-2.0	2.8	29	95
Hip	9	154	4	29	118	9	27	4	-1.9	2.9*	30	94
Diaph	15*	163*	6*	32*	124*	16	34	6*	1.5*	3.2*	35*	91
Chest	22*	171*	9*	37*	130*	21*	40*	8*	2.1*	3.7*	40*	91
Neck	27*	167*	12*	41*	134*	28*	49*	12*	3.8*	4.2*	43*	97

All pressures = mmHg; CO=L/min; Sv= ml; Hr=b/m*= different from Contr at $p<0.5$ Results There was no significant increase in most of the measured parameters until WI above the hip. The large increases in CVP, LVEDP and RVEDP with WI to the neck indicate a significant passive increase in thoracic blood volume. Hr did not change significantly, therefore, the 62% and 59% increase in Co and Sv, respectively, were the result of the Frank-Starling mechanism and not an inotropic response. MAP increased only 16%, suggesting a significant decrease in peripheral resistance. Comment Recent swine data suggest a similar increase in thoracic venous blood volume using a pneumatic extended coverage anti-G suit from the diaphragm to the ankles."

Burns JW, Robinson JL, Fanton JW, Davis H, Richardson LA, Laughlin MH. Acceptable level of coronary artery disease (CAD): A preliminary study. (Abstract) Aviat. Space Environ. Med. 1993;64:194 and AL/DF-TP-1994-0004.

Abstract: "INTRODUCTION. Current Air Force policy restricts pilots, with even minimal CAD, from flying high-performance aircraft. Liberalization of this policy is being considered, and additional data are needed for a rational decision. METHODS. Eleven miniature swine (MS) were place on a high cholesterol/high fat diet (15 % beef tallow) for one year. Five additional MS were maintained on a standard control swine diet (no cholesterol) over the same time. A vascular access port (VAP) was surgically placed into t he superior vena cava and brought under the skin to the left side of the neck behind the ear. The 16 un-anesthetized MS were $+G_z$-stressed one or two times each, using an alternating 4-8 $+G_z$ simulated aerial combat maneuver (SACM) with 10 sec at each $+G_z$ level. The MS were protected with an abdominal bladder anti-G suit. At the end of the SACM Tc-99 was infused into the VAP and MS were scanned for myocardial perfusion approximately one hour later. RESULTS. Three MS died before data collection, one at 6

months and two at 9 months. Histopathology showed moderate-to-severe CAD in the three MS. Control and experimental plasma cholesterol levels (mg%) were : total=77 and 422: ratio =2.3 and 8.6: LDL=35 and 353, respectively. Dysrhythmias and T-wave alterations during $+G_z$ were seen equally in both the control and experimental MS. However, ST-T segment changes during $+G_z$ were observed in all of the experimental MS but none of the control MS. Coronary Histopathology showed normal vessels from the control MS and stenoses ranging from 10-95% from the experimental MS. There was a positive relationship between ST-T changes and abnormal myocardial perfusion scans. COMMENT. Additional studies are planned to identify the severity of CAD at the earliest detectable indication of ischemia during $+G_z$ and treadmill stress using the MS."

9. LIFE SUPPORT EQUIPMENT DEVELOPMENT LABORATORY

The contractor shall operate and maintain a softgoods shop to design, develop, and manufacture the following types of experimental life support equipment: a. Anti-G suits; b.. State-of-the-art pressure suits; c. Combination G/Chest counter-pressure garment; e. Liquid and air conditioned garments for protection against thermal stress.

Accomplishments

KLSI provided a Soft-goods Fabrication Technician to operate the Life Support Equipment Development Laboratory fabricate, alter, modify or repair ATAGS, CSU-13B/P anti-G suits, and other items of life support equipment.

Products delivered:

ATAGS Fabricated (Contract Total)	77*
ATAGS Modified/Altered/Repaired	480
CSU-13B/P G-suits Modified/Altered/Repaired	360
Other Life Support Equipment Modified/Altered/Repaired	420

*Includes ATAGS fabricated under T.O.s 7, 12 and 16.

10. TESTING OF LIFE SUPPORT EQUIPMENT

The contractor shall recommend and perform tests on various life support items or equipment in the AL centrifuge or Research Chambers. The equipment items include: Anti-G valves, anti-G suits, transducers, regulators, oxygen masks, and any other equipment that may be determined necessary by the Government. (DIN A003, A011)

Accomplishments

KLSI provided a life support equipment engineer to operate the Life Support Equipment Testing Laboratory (LSETL) and conduct unmanned testing of life support equipment. Efforts included the development and validation of test procedures, developing and validating G-suit drawings and patterns (ATAGS and CSU-13B/P), and conducting G-suit testing. Specific tests included ATAGS volume determinations, suit inflation time assessments, leak testing, pressure tests, altitude tests, heat and cold storage tests, restraint buckle strength tests and endurance testing. At a minimum, all G-suits fabricated or modified/altered/repaired under section no. 9 were pressure and leak tested. In addition, the (LSETL) conducted/supported all unmanned testing documented under T.O.s 3, 12 and 16.

Research reports (DIN A005, DIN A009, DIN A010, and/or DIN A016) from this effort include:

Perez R III, Ohlhausen JH, Preen PJ. A reliable and repeatable method for volume calculation of pressurized garments. 31st Annual SAFE Symposium Proceedings. 1993;227-30.

Abstract: "A rapid, accurate and efficient method to conduct inflation, volume and leak tests on pressure containing personal protective garments was developed and validated. The new system consists of a computer data acquisition and process control system that integrates flow rate over time to calculate volume. Validation of the new test system was accomplished by comparing the volumes calculated by the computer with volumes actually measured via a wet spirometer. Results from the validation study showed that the computerized system was highly accurate. In addition, the computerized system allows suits to be rapidly and effectively evaluated."

Ripley GL, Perez R, Bauer DH. Procedures and metrics for anti-G suit evaluations. 31st Annual SAFE Symposium Proceedings. p. 231-4. SAFE J. 1993;24:37-40.

Abstract: "The ATAGS (Advanced Technology Anti-G Suit) design process initially relied on comments made by human test subjects to subjectively evaluate the effects of design changes on inflation characteristics. A standardized test method was needed to objectively quantify the effects of the design changes and also to compare the inflation characteristics of other anti-G suits. Therefore, a test was designed to measure the filling characteristics of different anti-G suits fitted to a standard mannequin. Several factors had to be considered in developing a test method that was both operationally significant and provided consistently valid data. The factors considered were: don/doff requirements, the effects of evacuation of the anti-G suits prior to testing, mannequin position and additional life support equipment worn with the anti-G suit. Parameters measured to assess the inflation characteristics were flow, fill times, and differential pressures in the suit."

11. SUBATMOSPHERIC RESEARCH

The contractor shall develop and validate a computer mathematical model which will determine the risk of altitude decompression sickness (DCS) associated with USAF high altitude and/or

space operations. The contractor shall develop computer software to be used by trained field personnel to predict the DCS risk associated with a given mission profile and which will also evaluate the efficacy of alternative counter-measures in reducing the DCS risk. The contractor shall insure the system is suitable to use for mission planning and to provide real time input to mission coordinators in the event of unexpected contingencies during mission execution. The contractor shall use the Armstrong Laboratory DCS data repository and data from other research centers in the formulation of this model. The contractor shall recommend, design, and conduct experiments to investigate the effects of different types of exercise, i.e., isotonic and isometric, in the etiology of DCS. The contractor shall operate a Hewlett-Packard Series 60 echo-imaging system for intravenous bubble detection in support of the research studies and document the results. (DIN A003, A011)

Accomplishments

Presentation of research results and concepts was provided as abstracted under specific protocol titles. Support was also provided to create briefings which described the Armstrong Laboratory High Altitude Protection Research activity and productivity. A spreadsheet based on the Air Force Research Laboratory (AFRL) Hypobaric Decompression Sickness Database was created to describe each AFRL decompression sickness protocol exposure resulting in hyperbaric oxygen treatment since the 1983 inception of the current database. The spreadsheet provided information on this concern to brief the AFRL. Briefing charts, figures, and other materials were also provided for a briefing to the USAF Surgeon General. Some invited presentations[3] also provided information derived from Air Force Laboratory High Altitude Protection Research activity. KLSI scientists provided information used during numerous consultations with individuals and organizations not located at the AFRL, Brooks AFB, TX.

AFRL Hypobaric Decompression Sickness Database Research

Some reports were developed by using results from several or all studies in the AFRL Hypobaric Decompression Sickness Database. Research reports (DIN A005, DIN A009, DIN A010, and/or DIN A016) from multiple protocols include:

Pilmanis AA, Meissner FW, Olson RM. Left ventricular gas emboli in six cases of altitude-induced decompression sickness. Aviat. Space Environ. Med. 1996;67:1092-6.

Abstract: "BACKGROUND. Ultrasonic techniques have demonstrated venous gas emboli (VGE) during exposure to high altitude. VGE per se have not been considered clinically hazardous. Arterial gas emboli (AGE), however, are viewed with great concern. The crossing-

[3] Webb JT. Applied Aerospace Physiology - Altitude. Technical Workshop at the 34th Annual SAFE Symposium. 1996.
Webb JT. Decompression sickness: A physiologic consideration in the design of future cockpit pressurization systems. Panel presentation at Aerospace Medical Association 65th Annual Scientific Meeting. May 1994, San Antonio, TX.
Webb JT. Denitrogenation efficiency and decompression sickness protection. Panel presentation at Aerospace Medical Association 65th Annual Scientific Meeting. May 1994, San Antonio, TX.

over of venous gas to the arterial circulation has not previously been seen in human subjects at altitude. This transfer may occur via either intracardiac defects, pulmonary shunts, or the pulmonary microcirculation. METHODS. A Hewlett Packard SONOS 1000 Echo Imaging System was used to monitor volunteer human subjects for gas emboli simultaneously in the right and left sides of the heart at simulated altitude in a chamber. Subjects found to have gas cross-over were evaluated for septal defects with either transthoracic or transesophageal echocardiography. Results: Previously unreported left ventricular gas emboli were observed with echo imaging in six subjects at altitude. In all 6 cases, at the time of AGE onset, the VGE scores were high from all monitored sites. Three subjects had noseptal defect, another had a small sinus venosus defect, a third had a patent foramen ovale, and one was not available for evaluation. Five of the cases became symptomatic at the time of AGE onset. CONCLUSIONS. Operational altitude exposures known to elicit high VGE counts in the majority of people should be avoided because of an increased risk of right-to-left gas cross-over and resulting potential for severe cerebral symptomatology."

Pilmanis AA, Webb JT. Altitude decompression sickness prediction: A simplified approach. 1995 SAFE Symposium Proceedings. 1995:501-9.

Abstract: "Altitude decompression sickness (DCS) is caused by evolving tissue nitrogen gas during decompression. The effects of the gas emboli on pain sensors, the respiratory system, and the nervous system impose limits on operational activities of pilots and astronauts. Successful prediction of DCS risk is compounded by variations primarily in altitude, exposure time, breathing mixture, level of denitrogenation, and exercise. The Armstrong Laboratory (AL) has an ongoing research program to investigate DCS risk and is developing a decompression computer model which will provide a means of predicting real-time risk throughout the altitude envelope of aerospace operations. In the interim, a set of figures has been developed to provide some guidance in operational planning. Data from the AL Hypobaric DCS Database were used along with conceptual relationships between the variables to derive risk assessment curves for three exposure conditions depending on preoxygenation and breathing mixture. The 5% and 50% risk curves allow estimates of "threshold" risk and "substantial" risk respectively, based on altitude and time at altitude."

Webb JT, Pilmanis AA. Decompression sickness risk versus time and altitude. 31st Annual SAFE Symposium Proceedings. 1994:212-6.

Abstract: "To predict altitude decompression sickness (DCS) risk with any degree of accuracy, one must weigh variables such as prebreathe time, rate of ascent/descent, time at altitude, altitude, mixed breathing gas (dependent upon altitude), and profiles with multiple ascents and descents. The length of research chamber exposures is fixed at simulated altitude. From an operational standpoint, variable time at altitude complicates any predictive capability, although a computer model to handle all of these variables is in development. In the interim, a retrospective study from the Armstrong Laboratory Decompression Sickness Research Database has produced risk curves which can be used to predict DCS or venous gas emboli (VGE) incidence as a function of time at various altitudes. We limited the data to: 1) zero-prebreathe exposures to greater than 20,000 ft breathing 50% O2, 50% N2; 2) zero-prebreathe exposures to less than 20,000 ft breathing 100%

O2.; and 3) 1-h prebreathe exposures to greater than 20,000 ft breathing 100% O2.. Using the curves, one can select a time/altitude of exposure and estimate the DCS and VGE percentage."

Webb JT, Pilmanis AA. Decompression sickness risk versus time at 22,500-30,000 feet. SAFE J. 1995;25:133-5.

Abstract: "Incidence of altitude decompression sickness (DCS) varies primarily with preoxygenation time, time at altitude, altitude, and exercise. With research chamber exposures of fixed length, reported incidence of DCS is typically reported as the percentage of subjects who experienced DCS during the total time of the exposures. Reporting only the final percentage of subjects with symptoms does not indicate the time-course of symptom development. Therefore, we have initiated a retrospective study of the Armstrong Laboratory Hypobaric Decompression Sickness Research Database records and produced curves of % DCS occurrence versus time of exposure; i.e., response curves. The data shown are limited to the first two h of exposure at 22,500 ft to 30,000 ft following a 1-h preoxygenation. These limits are consistent with current recommendations for operational missions. Using these response curves, one can determine the percentage of DCS observed as a function of altitude and exposure time."

Webb JT, Pilmanis AA. Denitrogenation Time vs. DCS at 30,000 ft.. (Abstract) Aviat. Space Environ. Med. 1996;67:667.

Abstract: "INTRODUCTION. Decompression sickness (DCS) is caused by decompression to a pressure which results in supersaturation with nitrogen, leading to bubbles in tissues and blood. Denitrogenation by breathing 100% oxygen prior to decompression is called prebreathing or preoxygenation. The relationship of preoxygenation time to DCS incidence was depicted by Waligora et al. (1987) as a linear regression line corresponding to 0%, 21%, and extrapolated to 40% DCS following 8, 4, and 1 h of preoxygenation, respectively. This contrasts with the exponential curve of measured nitrogen elimination, particularly in the time period under 4 h. The Armstrong Laboratory (AL) Hypobaric DCS Research Database was used to provide information on the symptom incidence versus preoxygenation relationship at preoxygenation times from 1-4 h. METHODS. The database contained information on 166 male subject exposures to altitudes of 29,500-30,000 ft (8,992-9,144 m) with resting preoxygenation times of1-4 h. The protocols required mild exercises during the 4 to 8-hexposures. RESULTS. The incidence of DCS following 4 h of resting preoxygenation was 20% during the AL study. Following 1-2.25 h of preoxygenation, the AL studies resulted in 67 to 56% DCS. CONCLUSION. These findings show that the relationship between DCS incidence and preoxygenation time is curvilinear rather than linear; showing a trend toward much higher levels of DCS with resting preoxygenation times under 3 h than shown with a straight line extrapolation. The curve appears to more closely follow the curve of nitrogen elimination than previously reported (Waligora et al., 1987)."

Webb JT, Pilmanis AA. Altitude decompression sickness risk prediction. 32nd Annual SAFE Symposium Proceedings. 1994;119-23.

Abstract: "Exposure to altitudes between 18,000 and 25,000 ft can cause decompression sickness (DCS). DCS can be prevented with sufficient denitrogenation, but excessive time spent

denitrogenating can adversely impact mission accomplishment. In response to a frequent demand for estimates of DCS risk and the need for better definition of denitrogenation requirements, an altitude DCS computerized model based on physical and physiological principles is being developed at the Armstrong Laboratory, Brooks AFB, TX. This model will be able to predict DCS incidence based on duration of denitrogenation time, variable altitude, and different breathing mixtures. However, until the model is completed and validated, current operational need for guidance in the altitude range of 18-25,000 ft has stimulated development of interim DCS risk prediction tables to provide risk assessments. The tables in this paper estimate the risk of DCS for various on-ground and in-flight preoxygenation time periods, and for heavy exercise versus rest during altitude exposure. Application of these tables to flight operations requires caution because the tables are based on extrapolation from a small number of chamber research studies."

Webb JT, Pilmanis AA. Altitude decompression sickness risk prediction. SAFE J. 1995;25:136-41.

Abstract: "Exposure to altitudes between 18,000 and 25,000 ft can cause decompression sickness (DCS). DCS can be prevented with sufficient denitrogenation, but excessive time spent denitrogenating can delay missions or increase the time needed for mission accomplishment. In response to frequent demands for estimates of DCS risk and the need for better definition of denitrogenation requirements, an altitude DCS computerized model based on physical and physiologic principles is being developed at the Armstrong Laboratory, Brooks AFB, TX. This model will be able to predict DCS incidence based on duration of denitrogenation time, variable altitude, and different breathing mixtures. However, until the model is completed and validated, current operational need for guidance in the altitude range of 18-25,000 ft has stimulated development of interim DCS risk prediction tables. The tables in this paper can be used to estimate the risk of DCS for various on-ground and in-flight preoxygenation time periods, and for heavy exercise versus rest during altitude exposure. Application of these tables to flight operations requires caution since these tables are based on estimates using limited data from a small number of chamber research studies."

Webb JT, Pilmanis AA. Impact of recent altitude physiology research on design of cockpit pressurization systems. 35th Annual SAFE Symposium Proceedings. 1997 [In Press].

Abstract: "Design of cockpit pressurization systems impacts operational exploitation of the maximal altitude capabilities of some aircraft. The U-2 exposes the pilot to a cockpit altitude of approximately 30,000 ft with a 3.8 psid pressurization system. Approximately 70% of active/retired U-2 pilots reported that decompression sickness (DCS) occurred during their career of flying 9-hour missions at this altitude. Design of the F-22 pressurization system was based on previous fighter aircraft systems which maintain 5.0 psi differential pressure above 23,000 ft. Unfortunately, the 60,000 ft planned cruise capability of the F-22 places the pilot at 22,500 ft. The recently-reported threshold for DCS while breathing 100% oxygen is approximately 21,000 ft. The threshold altitude, which is lower than USAF and FAA regulations currently allow for unpressurized flight, implies a need for greater cockpit differential pressure for the F-22 and reinforces the need for breathing 100% oxygen prior to and including the high altitude portions of

the flight profile. Increasing the cockpit differential pressure to keep the pilot at less than 21,000 ft would eliminate the vast majority of DCS cases. Breathing 100% oxygen during this period would provide additional protection from hypoxia in the event of unexpected rapid decompression. Another recent finding indicates that denitrogenation by breathing 100% oxygen at altitudes up to 16,000 ft is as effective as ground-level prebreathing. In addition, gas emboli formation at 16,000 ft is lower than at higher altitudes. Continuing research in altitude physiology would help define optimal design parameters.

Computer Mathematical Model Development

A feasibility study completed just prior to the beginning of this contract (Sulaiman, et al., 1994) indicated that development of a computer model of decompression sickness risk was, indeed, feasible. Our first effort under this contract was to conduct a broad and detailed literature search and identify a number of papers[4] to use as guides during the development of the model. The bubble growth or collapse phenomenon in liquids appears in such diverse fields as boiling, cavitation, composite materials to manufacture void-free high performance materials, bubble removal during glassmaking, measuring the elongational viscosity of liquids, polymer processing (different categories of foam processing), microgravity and hypo/hyper-baric exposures. The citations were entered in a database (DIN A007) for retrieval and incorporation in reports emanating from further study.

The next effort was to create a mathematical bubble growth model which would calculate the time of onset of the maximum bubble radius, due to a hypobaric exposure, depending on altitude (pressure), preoxygenation time, and exercise level. The time of onset of the maximum bubble radius was then used as one of the predictive factors to calculate the risk function from a statistical model (parametric). It was assumed that the survival time has a known distribution (loglogistic) which depends on a vector of risk factors $\mathbf{x}$ (other components of the vector $\mathbf{x}$ are altitude, preoxygenation time, time of exposure at altitude, and exercise level) (Kannan et al., 1997).

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[4] Arefmanesh A, Advani S, Michaelides E. An accurate numerical solution for mass diffusion-induced bubble growth in viscous liquids containing limited dissolved gas. Int. J. Heat Mass Transfer. 1992; 35(7):1711-22.

Barlow EJ, Langlois WE. Diffusion of gas from a liquid into an expanding bubble. IBM J. Res. Dev. 1962; 6:329-37.

Duda JL, Vrentas JS. Mathematical analysis of bubble dissolution. A.I.Ch.E.J. 1969; 15(3):351-6.

Duda JL, Vrentas JS. Perturbation solutions of diffusion-controlled moving boundary problems. Chem. Engng. Sci. 1969; 24:461-70.

Epstein PS, Plesset MS. On the stability of gas bubbles in liquid-gas solutions. J. Chem. Physics. 1950; 18:1505-9.

Readey DW, Cooper AR. Molecular diffusion with a moving boundary and spherical symmetry. Chem Engng. Sci. 1966; 21:917-22.

Roberts GO. Computational meshes for boundary layer problems. Proc. Second Int. Conf. Num. Methods Fluid Dyn., Lecture Notes in Physics, vol. 8, Springer-Verlag, New York, 1971; 171-7.

Subramanian RS, Chi B. Bubble dissolution with chemical reaction. Chem. Engng. Sci. 1980; 35:2185-94.

Weinberg MC, Subramanian RS. The dissolution of a stationary bubble enhanced by chemical reaction. Chem. Engng. Sci. 1981; 36(12):1955-65.

The bubble growth process is, in general, complicated. It involves simultaneous mass, momentum and energy transfer between the expanding bubble and the soft tissue surrounding it. For example, in the case of mass diffusion-induced growth of a gas bubble, the movement of the gas-liquid interface depends on the gas pressure inside the bubble through momentum transfer. On the other hand, the gas pressure and the bubble radius are related to each other and to the ratio of gas diffusion through the conservation of mass. In addition, the rate of gas diffusion depends on movement of the interface as described by the diffusion equation. Hence, the three equations, momentum, mass balance, and convection-diffusion equations, are highly coupled, nonlinear, and must be solved numerically (Petropoulos, 1995).

The model evolved to its current form consisting of a convection-diffusion equation with a sink term on the right hand side (in order to account for the effect of the perfusion of the blood in the process), the momentum equation, and the mass balance equation. All three equations are expressed in spherical coordinates. The amount of liquid and dissolved gas immediately surrounding the bubble is assumed to be finite (Petropoulos, 1995) to account for the effect of other bubbles growing simultaneously in close proximity (bubble density). The concentration satisfies a Dirichlet boundary condition ($C=k_hP_g$; Henry's Law) at the bubble boundary and a non-flux (Neumann) boundary condition at the outer shell surface. The non-flux condition restricts any gas exchange and limits the dissolved gas that is to be used by the bubble.

A numerical method was developed for the solution of the bubble growth model. A 2nd-order, accurate, finite difference method was used to discretize the convection-diffusion equation. The convection-diffusion equation describes the space-time evolution of the gas concentration outside the bubble. Since the concentration of a gas changes most rapidly in a boundary layer near the bubble surface, a mapping transformation was employed. The mapping transformation is equivalent to a stretching from the physical spatial coordinate, to a spatial coordinate in which there is no boundary layer. The 4th-order accurate Runge-Kutta method was employed to solve the ordinary differential equations (meaning the mass balance and the momentum equation) which were driven by the concentration gradient on the bubble surface and govern the time evolution of the bubble radius and its interior pressure (Petropoulos, 1995).

Research reports (DIN A005, DIN A009, DIN A010, and/or DIN A016) from this effort include:

Kannan N, Petropoulos L, Raychaudhuri A, Pilmanis AA. An altitude decompression sickness risk assessment model. (Abstract) Aviat. Space Environ. Med. 1997;68:625.

Abstract: "INTRODUCTION. Decompression Sickness (DCS) results from the evolution of nitrogen bubbles in tissues caused by reducing ambient pressure. In this study, a DCS risk assessment model was developed combining survival analysis techniques and a dynamic system describing bubble growth. METHODS. A data set of exposures of human subjects to simulate altitude at the Armstrong Laboratory provided information on the time of occurrence of bubbles and their corresponding grade (Spencer scale). The loglogistic distribution was used to model the symptom onset time, assuming that the probability of DCS is a function of altitude, preoxygenation time, exposure time, exercise, and the time of onset of maximum bubble grade. Maximum likelihood methods were used to obtain the parameter estimates. RESULTS. The fitted

model indicated that the time of onset of the maximum bubble grade was the most significant factor in predicting the risk of DCS. This combined model was used to predict the risk of DCS for a variety of exposure profiles. The table provides the predicted probabilities from the model, with and without bubble growth data, and the observed DCS rates in the database for two example exposure profiles. DISCUSSION. The predicted and observed probabilities agreed closely as illustrated in the table. For the exposure profile with zero preoxygenation time, the combined model provided more accurate predictions than the model ignoring the bubble data. CONCLUSION. The risk assessment model developed using bubble data provides accurate predictions of DCS risk for a variety of exposure profiles.

Exposure Profiles	Observed from the USAF database	Model prediction without bubble data	Model prediction including bubble data
25,000ft / zero preoxygenation / mild exercise / 240 minute exposure	83.3%	60.9%	85.7%
29,500ft / 75 minutes preoxygenation / mild exercise / 240 minute exposure	55.8%	64.8%	56.4%

Petropoulos L, Pilmanis AA. A mass diffusion-induced bubble growth model for altitude exposure. (Abstract) Aviat. Space Environ. Med. 1997;68:625.

Abstract: "INTRODUCTION. Decompression sickness (DCS) is a disease caused by evolved gas which occurs when living tissue is exposed to a reduction in ambient pressure. Modeling of gas bubble growth is of primary importance to the development of methods for DCS risk prediction. METHODS. A system of equations that describe the growth of gas bubbles after a given decompression event was developed to determine accurately the time of onset of the maximum bubble sizes. These gas bubbles are assumed to grow while surrounded by soft tissue which contains a limited amount of dissolved inert gas. A sink term in the diffusion equation accounted for the uniform loss of gas from the tissue due to perfusion. A numerical method was developed for the solution of the bubble growth model using finite differences, and special emphasis was given to the effect of diffusivity (D) and the perfusion rate coefficient (k). RESULTS. As a reference point, we used a decompression profile to 30,000 ft with k=0.02 and D=0.0013cm2 min-1 . When the diffusivity of the gas was doubled, the bubble doubled in size in the same amount of time. When the diffusivity was kept constant and the perfusion rate doubled, the concentration gradient at the bubble boundary decreased because it is a function of the perfusion rate. The bubble reached its maximum size quicker, that size was 60% smaller. DISCUSSION. When we increase the diffusivity, the speed of the gas moving towards the bubble increased. Thus, the bubble was able to consume more gas from the surrounding tissue before the gas was lost to perfusion. Similarly, when the perfusion rate was increased, the bubble absorbed less gas and the concentration gradient reached equilibrium about ten minutes faster.

CONCLUSION. Higher perfusion rate coefficients will lower the concentration gradient at the bubble boundary and decrease the expected time of onset to maximum bubble size, and to final bubble size. An increase in diffusivity will result in an analogous increase in the maximum bubble size."

Petropoulos LJ, Pilmanis AA. Theoretical analysis of the diffusion/perfusion-controlled growth of multi-component gas bubbles during hypobaric decompression. (Abstract) Aviat. Space Environ. Med. 1998;69:[In Press].

Abstract: "INTRODUCTION. Schedules utilizing inert gas switching to reduce risk of decompression sickness (DCS) have been used in diving but have had limited application in the hypobaric field. Several mathematical models have been developed to describe growth and decay of tissue gas bubbles due to a hypobaric decompression. The majority of these models are based on the assumption that nitrogen is the primary factor controlling the process. Their equations were, therefore, formulated to describe a single gas dynamic behavior. We have recently developed a model, which describes the behavior of an isolated, stationary, multi-component gas bubble in a tissue containing several gases. The model is capable of including metabolic gases (i.e., O2 , CO2), or other inert gases (i.e., Ar). The model was designed to account for gases with zero initial concentrations, to be able to estimate the effect of inert gas switching on bubble growth. METHODS. The conservation of momentum along with the conservation of mass and a convection-diffusion-perfusion equation were used in order to describe the radius profile over time. All of the gases are treated simultaneously and the system of equations was solved numerically using the finite difference method. RESULTS. The multi-component model predicts that the last stages of the dissolution process can be greatly influenced by gases with low concentration and low diffusivity and/or solubility, either originally present in the bubble or previously dissolved in the tissue. Newly introduced gases with low diffusivity and low solubility but high concentration in the breathing mixture caused the bubble radius to decrease significantly before it began to increase. This "lag time" in growth also required the presence, within the bubble, of a high solubility, high diffusivity gas with large initial concentration. CONCLUSION. The multi-component bubble growth model predicts that by selecting gases with appropriate diffusivity/solubility characteristics for introduction into the breathing mixture, a delay in bubble growth will occur. This lag time in bubble growth may be exploited for DCS prevention by utilizing inert gas switching."

Petropoulos LJ. Hypobaric decompression sickness model development (Part I): Diffusion of inert gas from a viscoelastic fluid (blood) into an expanding gas phase. AL/CF-TR-1994-0029. 1994;22pp.

Abstract: "Bubble growth within a volume of isothermal viscoelastic liquid containing uniformly distributed dissolved gas is considered. A nonlinear viscoelastic constitutive equation is used as a blood model. The problem of characterizing this growth-by-mass-transfer is being treated extensively, in order to better understand both the behavior of bubble growth due to supersaturation and its effects on altitude decompression sickness."

Petropoulos LJ, Petropoulos PG, Pilmanis AA. Mathematical analysis of bubble growth models applied to altitude decompression sickness. Math. Biosci. 1998;[In Prep].

Abstract: "In order to have a rigorous model of one of the factors that affects the probability of occurrence of decompression sickness (DCS), a system of equations was developed that describes the growth of gas bubbles after a given decompression event. These gas bubbles are assumed to grow while surrounded by soft tissue containing a limited amount of dissolved inert gas. A sink term in the diffusion equation accounted for the uniform loss of gas in the tissue due to perfusion. A numerical method was developed for the solution of the bubble growth model. From the full system of equations we systematically extract, through a cascade of physically motivated assumptions, the two subsets of equations known as the quasi-stationary and the quasi-steady state approximations. Special emphasis was given to the assumptions necessary to derive these approximate models in order to delineate the physical situations for which these assumptions hold and produce dependable results. An overview is given of the conditions under which the approximate solutions might produce erroneous results. The utility of the approximate solutions is limited since the spectrum of the decompression scenarios is greater than the narrow parameter range in which the approximate solutions can be trusted to produce valid results. We conclude that the numerical solution of the full set of equations is preferable to the quasi-steady state and quasi-stationary models derived previously."

Petropoulos LP, Pilmanis AA. The role of bubble density, diffusivity and altitude on the bubble growth process in a hypobaric environment. (Abstract) Aviat. Space Environ. Med. 1995;66:479.

Abstract: "INTRODUCTION. The probability of Decompression Sickness (DCS) after any given decompression is assumed to be a function of various environmental and physiologic factors. One of these factors is the size of gas bubbles in the blood and other tissues. A mathematical representation of the diffusion-induced bubble growth process was developed and solved numerically to examine how various physiological parameters affect the growth of these bubbles in plasma. This bubble growth model will serve as one of the basic building blocks in the development of a USAF altitude DCS computer. The DCS computer will provide for both predictive and real-time risk assessment capability. METHOD. Basic principles such as the conservation of momentum (in its stress tensor form), the conservation of mass, and a diffusion equation were taken under consideration when the set of equations representing the bubble growth process were constructed. The numerical methods used to solve the coupled set of equations included a fourth order Runge-Kutta method for the ordinary differential equation system and a forward-time central-space scheme for the diffusion equation. A stretching transformation was also used on the diffusion equation to account for the large concentration difference existing on the bubble boundary. RESULTS. It was found that as the thickness of the liquid shell surrounding the bubble increased, the time to reach equilibrium radius also increased. Also, the equilibrium radius was larger since the mass of the gas within the shell increased with the shell's increased thickness. An increase in the diffusion coefficient accelerated the diffusion process; therefore, the bubble attained its equilibrium radius faster. Higher initial pressure difference at the bubble boundary resulted in larger final bubble sizes and sorter times to reach the asymptotic stage (and vice versa). CONCLUSION. The described bubble growth model produced

results consistent with those predicted by the physics of the problem. Also, the required growth time was very fast (up to 1 minute) and agreed with experimental values."

Sulaiman ZM, Scoggins TE, Pilmanis AA, Ripley PE, Melkonian A, Wang Y. Development of an operational altitude decompression sickness computer model: Feasibility study results. AL/CF-SR-1994-0032. Aug;111pp.

Abstract: "In response to the need for a standardized methodology for altitude decompression sickness risk assessment across the wide range of exposures encountered in USAF flight operations, the Armstrong Laboratory's Crew Technology Division initiated a research program in this area in late 1989. The focus of work has been on determining whether development of an operational altitude decompression computer for both predictive and real-time DCS risk assessment is feasible, given the current level of understanding about altitude decompression sickness, the amount of available experimental data, and the inherent variability in individual susceptibility to altitude DCS. The results of this feasibility study indicate that although some technical risk is involved, development of the proposed altitude decompression computer is feasible. This was demonstrated through the implementation of a simplified, preliminary model for altitude DCS risk assessment. This technical report documents the work accomplished during this research effort and provides a road map for development of the desired operational altitude decompression computer."

A specific protocol was developed as part of a model validation process. The protocol was based, in part, on guidelines used to validate hyperbaric decompression models[5].

DCS Model Validation Study

Scientific support was provided to write and review the protocol "Decompression Sickness (DCS) Model Validation" (DIN A020). Scientific and technical support were provided during conduct of the protocol [see Section 26.20].

AFRL Hypobaric DCS Research Database

The database includes information gathered from the use of the HP SONOS 1000 Echo-Imaging System, as well as descriptive information obtained before, during, and following each subject altitude exposure. Subject-exposure data sheets were prepared for each exposure until the database was transitioned to a Microsoft Access database [see Section 26.20], after which time the data were entered directly from workbooks and subject worksheets (DIN A004).

[5] Schneider HR, Hamilton, RW. Validation of decompression tables. Undersea and Hyperbaric Medical Society, Bethesda. 1989.

Experimental Investigation of Exercise Effects on Decompression Sickness.

Several protocols involved exercise during or before exposure as a variable. Each protocol required development and USAF Surgeon General's Office approval (DIN A011). Specific test plans were also developed (DIN A020) and approved prior to the first human subject exposure.

Effect of Exercise on Altitude Decompression Sickness

Scientific monitoring and writing, technical support, and exercise physiologist support activities were provided for the protocol "Effect of Exercise on Altitude Decompression Sickness" (AL ACHE #91-07, 25Feb91; addendum to ACHE 90-32 and 87-15). This protocol was designed to determine if there is a difference between upper and lower body exercise and between straining exercises (isometric) and exercises involving limb movement (dynamic). One-hundred-forty-one subject-exposures were accomplished. See Section 26.08 for research reports emanating primarily from the task order support of this effort.

Research reports (DIN A005, DIN A009, DIN A010, and/or DIN A016) from this protocol include:

Fischer MD, Wiegman JF, McLean SA, Olson RM. Evaluation of four different exercise types for use in altitude decompression sickness studies. 30th Annual SAFE Symposium Proceedings. 1993;102-5.

Abstract: "A study is ongoing at the Armstrong Laboratory, Brooks AFB, to determine effects of four types of exercise on altitude decompression sickness (DCS). The four types of exercise (isometric arm or leg, isotonic arm or leg) simulate events that may occur during high altitude reconnaissance flight or extravehicular activity in space. For the study, it is imperative that subjects perform equivalent work, while exercising, during exposure to altitude. The purpose of this paper is to describe a procedure to equate work, as measured by $\dot{V}O_2$ (ml/min), for the four exercise types. In four separate sessions, subjects (N=13) performed exercise, at varying percentages of their maximal strengths, while oxygen consumption data were recorded. From these data, exercise intensities for each exercise type were selected that would elicit a similar $\dot{V}O_2$. In four additional sessions, the selected work loads were verified during repeated 12-min exercise bouts. An analysis of variance (ANOVA) was performed to compare the 12-min average $\dot{V}O_2$ for the four exercise types. Mean $\dot{V}O_2$ of 388, 388, 385, and 392 ml/min for isometric arm and leg and for isotonic arm and leg, respectively, were not significantly different. Results show that the prescribed procedures are a valid method that can be used to equate four uniquely different types of exercise. These procedures provide a quantifiable tool for relating DCS to type of exercise, thus giving airframe manufacturers some insight into the type of work station necessary to avoid exercise-related DCS."

Olson RM, Pilmanis AA, Webb JT. Decompression sickness risk and the mode of exercise at altitude. (Abstract) Aviat. Space Environ. Med. 1995;66:491. (see Section 26.8 for abstract)

Pilmanis AA, Olson RM, Fischer MD, Wiegman JF, Webb JT. Exercise-induced altitude decompression sickness. Aviat. Space Environ. Med. [In Review] (see Section 26.8 for abstract).

Effects of Prebreathe while Exercising on DCS

Scientific monitoring, technical support [also see Section 26.06], and exercise physiologist support activities were provided for the protocol "Effect of Prebreathe with 100% Oxygen while Exercising on Incidence of Decompression Sickness (DCS)" (AL ACHE #89-25B, addendum, 2Jul92; formerly USAFSAM ACHE #89-25, 15May90). This protocol tested the feasibility of using exercise to enhance denitrogenation by increasing perfusion and ventilation during prebreathe.

During the ground-based exercise tests, subjects were monitored in accordance with guidelines established by the American College of Sports Medicine for exercise testing (Am. Coll. Sports Med., 1995) and AL directives on medical monitoring of exercising subjects. The peak[6] oxygen uptake was determined for each subject in order to determine an appropriate work rate (Kp at 50 rpm) to use during prebreathing for the hypobaric exposures. Standard electrocardiographic electrodes were applied prior to performing the test for aerobic capacity so heart rhythm and rate could be monitored. Expiratory gasses were collected and analyzed using the SensorMedics 2900Z Metabolic Measurement Cart (SensorMedics Corporation, Yarba Linda, CA). The test was continued to volitional or physiological maximal effort, which ever occurred first. Specific reasons for test termination included:

i. subject request to terminate test

ii. subject unable to continue test (i.e., volitional maximum)

iii. failure of subject oxygen consumption to increase with an increase in work demand with confirmation from elevated respiratory exchange ratio (≤1.15) and/or heart rate greater than age estimated maximum

iv. onset of angina or angina-like symptoms

v. significant drop (20 mm Hg) in systolic blood pressure or failure of systolic blood pressure to increase in response to an increase in work demand.

vi. excessive rise in blood pressure (systolic>260 mm Hg; diastolic >115 mm Hg)

[6] The max test involved the subject achieving their maximal oxygen uptake. The term "peak" is used here because most people did not achieve their "maximal oxygen uptake" while performing either leg or leg and arm cycle ergometry.

vii. subject exhibited signs of poor perfusion such as lightheadedness, confusion, ataxia, pallor, cyanosis, nausea or cold/clammy skin

viii. ECG abnormalities such as a pronounced ECG change from baseline (i.e., >2mm of horizontal/down sloping ST-segment depression or >2mm of ST-segment elevation), less serious arrhythmias (supraventricular tachycardia) and exercise-induced bundle branch block indistinguishable from ventricular tachycardia

ix. dyspnea

x. equipment failure

A Monarch 818E leg ergometer was used to determine VO_{2peak} with leg ergometry and the subject maintained a consistent rate between 50 and 70 rpm during all tests. A second Monarch 818E leg ergometer mounted and modified to allow simultaneous arm ergometry was used during subsequent tests. The arm ergometry was accomplished at a consistent rate between 40 and 50 rpm.

For the leg and arm VO_{2peak} test the resistance for the arm exercise was set to approximately 20% of the work rate (Kp*rpm*flywheel diameter) determined to elicit VO_{2peak} during the legs-only test. During the leg and arm VO_{2peak} test, the subjects exercised their arms with a Monarch 818E ergometer mounted in tandem with another Monarch 818E ergometer used for the leg exercise. The leg and arm VO_{2peak} test result was used to calculate work rate at 50-70 rpm on the legs and 40-50 rpm on the arms needed to elicit 75% of VO_{2peak} during a subsequent 10-min dual-cycle test using the following formulas:

Leg Exercise kp= ((((ml O_2/min from leg + arm VO_{2peak}) X 0.75)-300)/2) X 0.83)/360

Arm Exercise kp = ((((ml O_2/min from leg + arm VO_{2peak}) X 0.75)-300)/2) X 0.17)/240

The "0.75" multiplier obtains 75% of the VO_{2peak}; the "0.83" and "0.17" multipliers obtain the proportion of total workload devoted to legs and arms, respectively; the "300" subtrahend is a constant; and the final divisor adjusts for rpm and flywheel travel per revolution, e.g. (6 m/rev) X 60 rpm = 360.

The 10-min dual-cycle exercise began with a 50-70-rpm leg ergometry warm-up consisting of 1-min at 1kp and a second minute at 2kp. At the beginning of the third minute, the arm ergometry at 40-50 rpm was initiated and the resistance was set to produce 75% of VO_{2peak} during the next 8 min of the 10-min exercise. VO_2 results from the last 5 min of the exercise were used to calculate the actual percent of VO_{2peak}. Heart rate recorded during the 75% of VO_{2peak} test was used in addition to the calculated resistances for legs and arms to monitor performance during the prebreathe exercise. If the heart rate during the prebreathe exercise varied appreciably relative to

the 75% dual-cycle test (5-10 bpm depending on the subject, phase of the exercise, and other conditions), the resistance was changed appropriately.

Fifty-nine subject-exposures were accomplished including performance assessment battery (PAB) testing and pre-exposure PAB training. A briefing on results from this protocol was presented at Beale AFB, CA for staff and physiologists working with the U-2 program (DIN A005). Other briefings were given to NASA personnel at NASA-JSC on several occasions and NASA-contracted researchers and NASA Headquarters personnel at a meeting in Galveston, TX coordinated by the Universities Space Research Association (DIN A005). A draft special report was delivered which describes practical application of the procedure in the U-2 environment (DIN A009). Research reports (DIN A005, DIN A009, DIN A010, and/or DIN A016) from this protocol include:

Heaps CL, Fischer MD, Webb JT. Dual-cycle ergometry as an exercise modality during prebreathe with 100% oxygen. (Abstract) Presentation at Space Operations Applications and Research Symposium. 1993;496.

Abstract: "In an effort to reduce prebreathe time requirements prior to extravehicular activities and high-altitude flights, a combined arm and leg exercise task (dual-cycle ergometry) has been integrated into a shortened prebreathe period. This exercise task proposes to enhance denitrogenation by incorporation of both upper and lower body musculature at a moderately high work intensity during prebreathe with 100% oxygen. Preliminary findings indicated peak oxygen consumption (VO_{2peak}) levels attained on the dual-cycle ergometer do not differ significantly from those levels attained on the treadmill. Eight male subjects were exercised to VO_{2peak} using leg-only cycle ergometry and dual-cycle ergometry on separate days. Preliminary data during dual-cycle ergometry showed arm work equaling 30% of the leg work rate at each stage of the incremental test resulted in arm fatigue in several subjects and a reduced VO_{2peak} compared to dual-cycle ergometry with arm work at 20%. Thus, the 20% workrate was used during the dual-cycle VO_{2peak} trial. On a third experimental day, subjects performed a 10 min exercise test at a work rate required to elicit 75% of VO_2 peak for each subject on the dual-cycle ergometer. Blood lactate response to the exercise was monitored as an objective measure of fatigue. Peak VO_2 levels attained on the leg-only and the dual-cycle ergometry tasks were not significantly different. Blood lactate levels were significantly elevated following the dual-cycle ergometry at 75% VO_{2peak} However, lactate levels show the expected rate of decline during recovery and, as demonstrated in the literature, should return to baseline levels within 30 min following exercise cessation. Thus, dual-cycle ergometry at 75% VO_{2peak} appears to be a valid exercise for use during prebreathe and should not contribute to fatigue during subsequent EVAs."

Heaps CL, Fischer MD, Wiegman JF, Webb JT. Blood lactate response to dual cycle ergometry at 75% VO_{2peak} (Abstract) Aviat. Space Environ. Med. 1993;64:420.

Abstract: "INTRODUCTION. A study is underway to determine the effect of combined arm and leg exercise, while breathing 100% oxygen, on subsequent incidence of decompression sickness (DCS) during simulated extravehicular activity (EVA) and high altitude flight. Concern

has been expressed in the literature that high blood lactate levels may contribute to the occurrence of DCS. The purpose of the present investigation was to determine the blood lactate response to this exercise task. METHODS. Eight male subjects were exercised to $\dot{V}O_{2peak}$ during combined arm and leg exercise (dual cycle ergometry). During the test, arm work equaled 20% of the leg work rate at each stage of the incremental test. The $\dot{V}O_{2peak}$ was obtained to determine the workload required to elicit approximately 75% of $\dot{V}O_{2peak}$ for each subject. On a subsequent day, subjects performed a 10 min exercise test on the dual cycle ergometer. Following the achievement of steady state, subjects exercised at approximately 75% of $\dot{V}O_{2peak}$ until the test was terminated and active recovery began. Blood lactate level (finger-stick) was measured prior to and 1,3,5 and 7 min following the cessation of the 10 min exercise test. An active recovery utilizing leg cycling only (30% $\dot{V}O_{2peak}$) was used to facilitate lactate clearance. RESULTS. Lactate levels increased from 1.2 + 0.2 mM prior to exercise to a peak level of 6.1 + 0.6 mM obtained at 1 min post-exercise (mean + SE; $P < 0.05$). Lactate levels declined progressively at 3, 5, and 7 min post-exercise (5.4 + 0.6, 5.2 + 0.5 and 4.6 + 0.5 mM, respectively); however, the levels remained significantly elevated vs. the pre-exercise level at each time point. CONCLUSION. The findings of this study indicate that blood lactate levels are significantly elevated following dual cycle ergometry at approximately 75% of $\dot{V}O_{2peak}$. However, these levels show the expected rate of decline during recovery and, as demonstrated in the literature, should decrease to approximately 50% of the peak level attained, within 15 min following exercise cessation. Thus, the lactate production during this sub-maximal exercise may not be of concern when performed 15 min prior to altitude exposure."

O'Connor RB, Baumgardner FW, Scoggins TE, Webb JT. Exercise as a factor in an altitude decompression sickness model. (Abstract) Aviat. Space Environ. Med. 1993;64:420.

Abstract: "INTRODUCTION. While previous research has shown exercise at altitude to increase rates of decompression sickness (DCS), varying end-point definitions of DCS and wide ranges of experimental conditions have made it difficult to quantify the contribution of exercise in the prediction of DCS. This study is to develop a method for incorporating exercise into an altitude DCS model and to quantify this predisposing factor. METHODS. DCS incidence and latency were determined for three groups of subjects performing varying exercise regimens. Additionally, the regimens were compared for oxygen consumption requirements. Altitude exposure data limits were 29,500-30,000 feet for a maximum of 4 hours following1 hr of prebreathing. Group A (N=32) performed only limb flexion every 15 minute cycle. Group B (N=26) combined the limb flexion with a 4 min/cycle of arm exercises. Group C (N=31) added 5 knee-bends and 5 arm-raises (with 5 lb. weights). Voluntary informed consent of subjects was obtained as required by AFR 169.3. RESULTS. Incidence of DCS and time of latency, respectively, for the three groups were:A=37.5% (198 min), B=66.7% (157 min), and C=77.4% (119 min). Differences in incidence and latency between the groups were highly significant ($p=0.004$ and 0.0002). Initial oxygen consumption results were: Exercise A = 307 ml/min, B = 344 ml/min, and C= 349 ml/min. CONCLUSION. With exercise at altitude, DCS incidence increases and latency decreases. However, the wide range of DCS incidence coupled with relatively small differences in oxygen consumption indicates that energy expenditure alone may not be a sufficient means of incorporating exercise into a DCS model."

Webb JT, Fischer M, Wiegman J, Pilmanis AA. Prebreathe enhancement with dual-cycle ergometry may increase decompression sickness protection. (Abstract) Aviat. Space Environ. Med. 1993;64:420.

Abstract: "INTRODUCTION. Extravehicular activity (EVA) from the space shuttle involves decompression to 4.3 psia, following a staged decompression schedule to 10.2 psia. This procedure requires decompression of the entire shuttle resulting in problems, e.g. reduced instrument cooling capacity and research data indicating a 20% decompression sickness (DCS) risk. Prebreathe procedures are needed to avoid severe venous gas emboli (VGE; precordial Doppler grades 3 and 4) and DCS, and to allow decompression from 14.7 psia to 4.3 psia without staged decompression. We are investigating the use of a ten-minute strenuous exercise period during a one-hour prebreathe as a means of enhancing denitrogenation by increasing ventilation and perfusion. METHODS. Male subjects were exposed to a pressure of 4.3 psia for 4 hours while performing moderate exercise. The prebreathe conditions consisted of 60 min of prebreathing, with or without 10 min of dual-cycle ergometry performed at 75% of the subject's maximal oxygen uptake. Subjects were monitored for intravascular gas emboli using a Hewlett-Packard SONOS 1000 Echo Imaging System and observed for DCS symptoms. RESULTS. The incidence of DCS and severe VGE following prebreathe with exercise was 0% and 40% respectively (N = 4), versus 86% and 71% after resting prebreathe (N = 7). CONCLUSION. Prebreathe enhancement with dual-cycle ergometry may offer better protection from development of DCS symptoms than resting prebreathe. Further testing has been initiated to allow statistical comparisons."

Webb JT, Fischer MD, Heaps CL, Pilmanis AA. Exercise with prebreathe appears to increase protection from decompression sickness. (Abstract) Seventh Annual Workshop on Space Operations, Applications, and Research (SOAR'93). NASA Conference Publication 3240. 1994;II:497-500.

Abstract: "Extravehicular activity (EVA) from the space shuttle involves the following staged decompression steps: 1) one hour of prebreathe with 100% oxygen; 2) a decompression of the entire Shuttle to 10.2psia for 12 hours which results in reduced instrument cooling capacity; 3) another prebreathe for 40 min; and 4) decompression to 4.3 psia for EVA. We are investigating the use of a one-hour prebreathe with 100% oxygen beginning with a ten-minute strenuous exercise period as a substitute for the staged decompression schedule described above. The exercise consisted of 10 min of dual-cycle ergometry performed at 75% of the subject's peak oxygen uptake to increase denitrogenation efficiency by increasing ventilation and perfusion. This was followed by 50 min of supine rest prior to the test exposures. The control exposures were preceded by 60 min of supine rest while prebreathing 100% oxygen. Exposure conditions for the twenty male subjects were 4.3 psia for 4 hours. Subjects were monitored for DCS symptoms. The incidence of DCS following prebreathe with exercise was 40% versus 75% following 60 min of supine rest. When tested in altitude decompression chambers at NASA-JSC, the staged decompression schedule resulted in a decompression sickness (DCS) incidence of 23% which is not significantly different from the exercise-enhanced prebreathe results. Prebreathe including exercise appears to be comparable to the protection afforded by the more lengthy staged

decompression schedule. When the study is completed later this year, data from the full complement of 26 subjects will enable better statistical analysis of the results."

Webb JT, Fischer MD, Heaps CL, Pilmanis AA. Exercise-enhanced preoxygenation increases protection from decompression sickness. Aviat. Space Environ. Med. 1996;67:618-24.

Abstract: "INTRODUCTION. Prevention of decompression sickness (DCS) during exposure to altitude equivalents of 30,000 ft (9,144 m) requires extensive denitrogenation. In preparation for extravehicular activity (EVA), present NASA policy is to denitrogenate using a 10.2 psia staged decompression of the entire shuttle for at least 12 h, including 100 min of preoxygenation (breathing 100% oxygen at 14.7 psia prior to decompression), before decompression to the 4.3 psia (30,000 ft; 9,144 m) suit pressure. This staged decompression provides the same or better protection from DCS as a 3.5- or 4-h preoxygenation used on earlier Shuttle EVAs. For high altitude reconnaissance flights at similar cockpit altitudes, a 1-h preoxygenation is currently required. METHODS. We have investigated the use of a 1-h and a 15-min preoxygenation period, each beginning with 10 min of dual-cycle ergometry performed at 75% of each subject's peak oxygen consumption ($\dot{V}O_{2peak}$) to enhance preoxygenation efficiency by increasing perfusion and ventilation. Male subjects accomplished a 1-h preoxygenation with exercise, a 15-min preoxygenation with exercise, or a 1-h resting preoxygenation before exposure to 4.3 psia for 4 h while performing light to moderate exercise. Results. Incidence of DCS following the 1-h preoxygenation with exercise (42%; n=26) was significantly less than that following the 1-h resting preoxygenation (77%; n=26). Incidence and onset of DCS following the 15-min preoxygenation with exercise (64%; n=22) was not significantly different from the incidence following the 1-h resting control. CONCLUSION. Preoxygenation with exercise has been shown to provide significantly improved DCS protection when compared with resting preoxygenation."

Webb JT, Fischer MD, Heaps CL, Pilmanis AA. Increased denitrogenation efficiency maintains decompression sickness protection while reducing prebreathe time. (Abstract) Aviat. Space Environ. Med. 1994;65:454.

Abstract: "INTRODUCTION. Denitrogenation by "prebreathing" 100% oxygen before exposure to high altitude to reduce decompression sickness (DCS) risk is standard practice for a number of flight operations. For example, aircrew in high altitude reconnaissance aircraft undergo decompression from ground-level pressure to approximately 4.3 psia (30,000 ft; 9146 m) during their missions. To avoid DCS, the aircrew are required to prebreathe for 1 h. We are investigating an alternative denitrogenation procedure consisting of a 10-min strenuous exercise period at the beginning of a 15-min total prebreathe time as a means of increasing denitrogenation efficiency by increasing ventilation and perfusion. METHODS. Eighteen male subjects were exposed to 4.3 psia for 4 hr while they performed moderate exercise. Prebreathe for the control exposure consisted of a 60-min supine, resting prebreathe. Prebreathe for the test exposure consisted of a 15-min prebreathe beginning with 10 min of dual-cycle ergometry performed at 75% of each subject's peak oxygen uptake. Subjects were observed for DCS symptoms and monitored for venous gas emboli (VGE) using a Hewlett-Packard SONOS 1000 Echo Imaging System. RESULTS. The incidence of DCS and VGE during the subjects' exposures to 4.3 psia following the 15-min prebreathe with exercise was 67% and 89% respectively, versus 78% and

78% after 1-h of resting prebreathe. CONCLUSION. A 15-min prebreathe involving dual-cycle ergometry offers similar protection from DCS symptoms as 1 h of resting prebreathe."

Preoxygenation with Exercise versus Rest (PE2)

Scientific development and monitoring, exercise physiologist support, and technical support activities were provided for the protocol "Preoxygenation with exercise versus rest: Effect on incidence of decompression sickness (DCS)" (AL ACHE #94-17A; SGO R94-040; approved 30Sep94). This protocol was designed to determine if increasing the duration of exercise from 10 to 15 minutes and the total prebreathe from 60 to 90 minutes would provided a significant reduction in DCS incidence from the previous protocol. The effectiveness of the further-enhanced exercise was compared with a 4-hour resting prebreathe profile in its effectiveness to reduce DCS during exposure to 30,000 ft for four hours. Exercise training and testing sessions were accomplished as during the earlier exercise with prebreathe study. One-hundred-seven subject exposures, 231 performance assessment battery training sessions, and 208 exercise training sessions were accomplished since the protocol began in July, 1995.

The leg and arm $\dot{V}O_{2peak}$ tests differed from the Effects of Prebreathe while Exercising on DCS study in that leg rpm was maintained at 60 and arm rpm at 40. During part of this study, an 881E arm ergometer was used for the arm exercise in lieu of a tandem-mounted 818E leg ergometer. During the 15-min, 75% of $\dot{V}O_{2peak}$ test, the leg and arm rpm was fixed at 50 and the last ten min was averaged to determine the $\dot{V}O_2$ instead of the last five min as was done during the 10-min, 75% of $\dot{V}O_{2peak}$ test. Expiratory gasses were collected and analyzed using the SensorMedics 2900Z Metabolic Measurement Cart (SensorMedics Corporation, Yarba Linda, CA) or the Rayfield Gas Analysis System. The progression of resistance for arms and legs during testing is shown below.

Minute of leg ergometry test	Leg Kp (60 rpm)	Arm Kp(40 rpm)
1	1.0	0
2	1.0	0
3	1.0	0
4	2.0	0
5	2.0	0
6	2.75	1.0
7	2.75	1.0
8	3.5	1.3
9	3.5	1.3
10	4.0	1.5
11	4.0	1.5
12	4.5	1.7
13	4.5	1.7
14	5.0	1.9
15	5.0	1.9

16	5.5	2.1
17	5.5	2.1
18	6.0	2.3
19	6.0	2.3

Research results (DIN A005, DIN A009, DIN A010, and/or DIN A016) from this ongoing protocol have been briefed to NASA personnel and are included in:

Webb JT, Pilmanis AA. A new preoxygenation procedure for extravehicular activity (EVA). 12th Man in Space Symposium: The future of humans in space. [In Press].

Abstract: "A 10.2 psi staged-decompression schedule ("camp-out procedure") or a 4-hour preoxygenation at 14.7 psi is required prior to extravehicular activity (EVA) to reduce decompression sickness (DCS) risk. Results of recent research at the Armstrong Laboratory showed that a 1-hour resting preoxygenation followed by a 4-hour, 4.3 psi exposure resulted in 77% DCS risk (N=26), while the same profile beginning with 10 min of exercise at 75% of VO_{2peak} during preoxygenation reduced the DCS risk to 42% (P<.03; N=26). A 4-hour preoxygenation without exercise followed by the 4.3 psi exposure resulted in 46% DCS risk (N=28; preliminary). The 1-hour preoxygenation with exercise and the 4-hour preoxygenation without exercise results were not significantly different. Elimination of either 3 hours of preoxygenation or 12 hours of staged-decompression are compelling reasons to consider incorporation of exercise-enhanced preoxygenation."

Webb JT, Pilmanis AA. Denitrogenation Time vs. DCS at 30,000 ft. (Abstract) Aviat. Space Environ. Med. 1996;67:667. (abstract in Section 11, AFRL Hypobaric Decompression Sickness Database Research)

Decompression Sickness at 35,000 ft

Scientific development and monitoring and technical support were provided for the protocol, "Decompression sickness on exposure to a simulated altitude of 35,000 feet" (AL ACHE #94-23; SGO R95-018, approved 21Dec94). This protocol was designed to determine the effect of a 3-hour exposure to 35,000 ft with 75 minutes of resting prebreathe when the exposure involved a) seated rest or b) intermittent exercise on a cycle ergometer. Eighty-four subject-exposures were accomplished by male and female subjects including both resting and exercising profiles. To preclude additional hazard for the inside observers at this high altitude, a robotic arm was used to control the echo-imaging probe.

Research reports (DIN A005, DIN A009, DIN A010, and/or DIN A016) from this protocol include:

Pilmanis AA, Ryles MT, Webb JT, O'Connor RB. Decompression sickness (DCS) risk at 35,000 feet. (Abstract) Aviat. Space Environ. Med. 1997;68: 621.

Abstract: "INTRODUCTION. During high altitude (35,000 ft) airdrop missions, exposed personnel include both parachutists and flight crew. DCS could significantly impair the effectiveness of such operations. This study investigated DCS at 35,000 ft at rest and with exercise. METHODS. Eighteen male volunteers were exposed to a simulated altitude of 35,000 feet (179 mmHg) for up to 3 hours, following 75 minutes of preoxygenation. Venous gas emboli (VGE) were monitored using a non-invasive Hewlett Packard SONOS 1000 Echo Imaging System. Moderate exercise consisted of pedaling an ergometer at 60 RPM with a 2.0 kp load for 3-min of each 10-min of exposure. The end-points were completion of the 3-hr exposure or symptoms of DCS. RESULTS. At 35,000 ft, there were significant differences between the final cumulative DCS risk of 50 % for rest and 94% when exercising (P=0.008). The mean DCS onset times were also different: 73 min for rest and 58 min for exercise (P=0.013). VGE incidence was 56% with rest and 89% with exercise (P=0.031). The mean VGE onset times were 47 min for rest and 32 min for exercise (P=0.035). Symptoms included primarily pain, with some cases of peripheral itching and tingling. All symptoms resolved during descent and no hyperbaric therapy was required. DISCUSSION. A large characteristic difference was found between the rest vs. exercise response curves, exercise resulting in very high levels of DCS and VGE. The cumulative incidence with exercise also increased very rapidly with time; 61% DCS and 83% VGE in the first 60 min. The lack of serious symptoms is consistent with the lengthy preoxygenation. CONCLUSION. These preliminary data indicate that the exposures for 30-min at 35,000 ft currently used by high altitude parachutists result in 12% DCS and 33% VGE if at rest, and 17% DCS and 56% VGE if exercising."

Hasser CJ, Nering JD, Pilmanis AA, Beene D, Webb JT. Teleoperated echocardiography for hypobaric aircrew research. (Abstract) Aviat. Space Environ. Med. 1996;67:666. [see 26.10]

Operation of Echo-Imaging System

An HP SONOS 1000 Echo-Imaging System was used to precordially monitor subjects during decompression sickness protocol exposures. The monitoring allows detection of venous gas emboli (VGE) and requires a technician trained in both echo-imaging with the HP SONOS 1000 Echo-Imaging System and the specialized application related to VGE detection [Section 11 and T.O. 10 and T.O. 20]. In addition, operation of the Puma Robotic Arm assembly for remote manipulation of the SONOS probe was incorporated as part of the technician support [T.O. 10 and T.O. 20]. Specifically, the study of decompression sickness at 35,000 ft required use of the remote arm technology. Use of the SONOS was required in all of the studies involving exercise as a variable and it was also used in the following studies:

Pulmonary Artery Pressure During Altitude Exposure

Technical support was provided for the protocol "Non-invasive measurement of pulmonary artery pressure in humans during altitude exposure" (AL ACHE #95-03B; SGO R95-040, 7Mar95). This ongoing protocol was designed to investigate the use of echo-imaging to detect pressure changes within the heart during altitude exposures with and without the presence of gas emboli. Thirteen subject-exposures were accomplished and monitored under this protocol.

Effect of Repeat Exposure on DCS

Scientific development, monitoring, and writing and technical support was provided for the protocol, "Effect of repeat exposures on incidence of decompression sickness (DCS)" (AL ACHE #96-03; SGO R96-012, 5Feb96). This protocol was designed to determine the effect of exposures to 25,000 feet without preoxygenation and involved continuous versus repeated exposures. Ninety-six subject-exposures were accomplished, completing the protocol.

Research reports (DIN A005, DIN A009, DIN A010, and/or DIN A016) from this protocol include:

Pilmanis AA, Webb JT, Krause KM. The effect of repeated altitude exposures on the incidence of decompression sickness. (Abstract) Aviat. Space Environ. Med. 1998;69:[In Press].

Abstract: "INTRODUCTION. Repeated altitude exposures occur during airdrop training, hypobaric chamber training, unpressurized flight, high altitude reconnaissance and extravehicular activity in space. Such exposures are thought to increase DCS risk. However, the literature is inconsistent and contradictory. We hypothesized that 4 short exposures to altitude would result in a higher incidence of DCS than a single exposure of equal duration. METHODS. Thirty-two subjects were exposed in a chamber to: Profile A: 2 hr continuous exposure (control); Profile B: four 30 min exposures with descent/ascent but no ground interval between each exposure; Profile C: four 30 min exposures with descent/ascent and 60 min ground interval breathing air between exposures. All exposures were to 25,000 ft, breathing 100% O_2, with no preoxygenation, and with four sets of mild exercises each hour. Precordial monitoring with an HP SONOS 1000 Echo-Imaging System was done every 15 min to provide venous gas emboli (VGE) data.

Exposure	DCS Incidence	DCS Onset(min)	VGE Incidence	VGE Onset(min)
A(control)	19 cases (59%)	70 ± 7	28 cases (88%)	32 ± 5
B	7 cases (22%)*	54 ± 10	21 cases (66%)*	40 ± 8
C	2 cases (6%)*	40 ± 13	21 cases (66%)*	43 ± 8

* Significantly different from profile A ($p<0.05$). Onset data are the mean ± SEM.

RESULTS. Of 28 symptomatic cases, Profile A resulted in 4 cases of respiratory/neurological symptoms, while B had one and C had none. All other cases involved pain, paresthsia, and/or skin symptoms. All symptoms resolved during recompression to ground level. DISCUSSION. These data suggest that the beneficial bubble size reduction during repressurization is significant and outweighs the negative effect of renitrogenation from breathing air at ground level. CONCLUSION. Contrary to current conventional wisdom, DCS risk with multiple short flights is less than with a single continuous long flight of equal duration.

Webb JT, Pilmanis AA, O'Connor RB. Zero-preoxygenation decompression sickness risk at 25,000 feet. (Abstract) Aviat. Space Environ. Med. 1997;68:621.

Abstract: "INTRODUCTION. Air Force Instruction 11-206 and Federal Aviation Regulation Parts 91.211 and 121.327-333 permit exposure to 25,000 ft without preoxygenation. Preliminary data from our laboratory indicated that the zero-preoxygenation 5% risk threshold for altitude decompression sickness (DCS) symptoms was no higher than 22,500ft. The present study documents zero-preoxygenation DCS risk at the currently-accepted limit of 25,000 ft. METHODS. Eighteen male subjects were exposed, without preoxygenation, to 25,000 ft simulated altitude, breathing 100% oxygen and performing mild exercises during exposure. Precordial venous gas emboli (VGE) were monitored with a Hewlett-Packard SONOS 1000 Echo-imaging System. Endpoints were DCS symptoms or completion of a 4-h exposure. RESULTS. The 25,000-ft exposures resulted in an 89% DCS and 89% VGE incidence with respective mean onset times of 71 and 27 min. Symptoms more serious than mild joint pain developed in 17% of the subjects. DISCUSSION. The DCS incidence at 25,000 ft was found to be very high with onset times as short as 9 min. These data were used with previous data to determine that the zero-preoxygenation 5% DCS risk threshold is 20,500 ft. Above 20,500 ft, the rapid increase in symptom incidence and short onset times demonstrate need to preoxygenate or limit exposure time to 30-min. CONCLUSION. Recommend USAF and FAA regulations be amended to recognize the risk of a zero-preoxygenation 5% DCS risk threshold at 20,500 ft."

Zero-prebreathe DCS below 25,000 feet

Scientific development, monitoring, writing, and technical support was provided for the protocol, "Decompression sickness protection below 25,000 feet using 100% oxygen without prebreathe" (AL ACHE #93-03A; SGO R93-010, 11May93; revision approved 23Feb95). This protocol was designed to identify the threshold of DCS with zero-prebreathe exposure and to further characterize the sigmoidal relationship between altitude and VGE occurrence. One-hundred-two subject-exposures were accomplished.

Research reports (DIN A005, DIN A009, DIN A010, and/or DIN A016) from this protocol include:

Pilmanis AA, Webb JT. The gender aspect of altitude-induced decompression sickness susceptibility. (Abstract) Aviat. Space Environ. Med. 1996;67:682 and DTIC #ADA328256.

Abstract: "An operational need exists for definition of the role of gender in decompression sickness (DCS) susceptibility and the physiologic basis of any such differences. Cockpit/cabin altitude environments in trainers and reconnaissance aircraft, and during airdrop and gunship operations, remain a potential hazard to male and female aircrews. Reports from over 700,000 training chamber exposures indicate females, principally flight nurses, are 4.6 times more susceptible to DCS than males, although the female DCS incidence was very low (< 0.23%). Published prospective research chamber studies addressing the gender aspect of DCS susceptibility have been scarce and equivocal. Additional research is needed to determine female susceptibility and incidence of DCS. Three prospective research chamber studies are in progress at the Armstrong Laboratory (AL) utilizing both male and female subjects and encompassing a wide range of altitude conditions. One protocol was developed to identify the threshold altitude for DCS with zero-preoxygenation. Another protocol was designed to test the hypothesis that

preoxygenation beginning with moderate exercise significantly increases effectiveness of denitrogenation. The third protocol was developed to test the effect of moderate exercise while decompressed on the incidence and onset of DCS symptoms. Inclusion of female subjects in these studies will provide considerable data for use in determining the impact of any gender-related differences in susceptibility and in developing adequate countermeasures for the aircrew."

Webb JT, Pilmanis AA. Defining the altitude threshold of decompression sickness. (Abstract) Aviat. Space Environ. Med. 1995;66:496.

Abstract: "INTRODUCTION. Preoxygenation by breathing 100% oxygen should be accomplished prior to exposure to altitudes where decompression sickness (DCS) may occur. Historically, 18,000 ft (1/2 ATA) has been described as the theoretical threshold of altitude DCS, although this has not been experimentally confirmed. METHODS. Male subjects were exposed one time, without preoxygenation, to one of the following altitudes for a maximum duration of 6-h: 11,500, 15,000, 16,500, 18,000, 19,800, 21,200, and 22,500 ft. The 70 subjects, 10 at each altitude, breathed 100% oxygen and performed mild exercises during the exposures. Incidence of venous gas emboli (VGE) was measured with a Hewlett-Packard SONOS 1000 Echo-imaging System. RESULTS. A 50% DCS incidence was observed at 22,500 ft with no incidence at any lower altitudes. Incidence of DCS at 22,500 ft is supported by the probit curve of VGE occurrence which shows 80% VGE at 22,500 ft, decreasing to 20% at 15,000 ft. CONCLUSION. A threshold altitude for DCS has been shown to be no higher than 22,500ft using 100% oxygen as the exposure breathing mixture. Zero-preoxygenation exposure to 22,500 ft requires preoxygenation to preclude symptoms from affecting operational performance."

Webb JT, Pilmanis AA. Altitude decompression sickness - Operational significance. In: Raising the operational ceiling - A workshop on the life support and physiological issues of flight at 60,000 feet and above. Proceedings. AL/CF-SR-1995-0021. 1995:33-43.

Abstract: "Raising the ceiling of current flight operations will have the effect of increasing the altitude exposure hazard and consequent incidence of decompression sickness (DCS) symptoms. In many cases, the current operational incidence of DCS is already a limiting factor and without increased protection that factor may become the controlling influence for operational planning of some mission scenarios. The F-22 will place the pilot at a cockpit cruise altitude of 22,500 ft; above the threshold of DCS with a latency for symptom onset within one hour (Webb and Pilmanis, 1995c). Use of 100% oxygen is necessary to provide additional protection and increased cabin pressure differential to at least 6 psid is highly recommended. Research is needed to further define the risk, predict the risk, and offer recommendations for avoidance of DCS symptoms."

Webb JT, Pilmanis AA, O'Connor RB. An abrupt zero-preoxygenation altitude threshold for decompression sickness symptoms. Aviat. Space Environ. Med. 1998;69:[In Press].

Abstract: "INTRODUCTION. The altitude threshold for decompression sickness (DCS) symptoms has been variously described as being 18,000 ft (5,487 m) to above 25,000 ft (7,620 m). Safety and efficiency of aerospace operations require more precise determination of the DCS

threshold. METHODS. One hundred fifteen male human-subjects were exposed to simulated altitude (11 at 11,500 ft; 10 at 15,000 ft; 8 at 16,500 ft; 10 at 18,100 ft; 10 at 19,800 ft; 20 at 21,200 ft; 20 at 22,500 ft; 10 at 23,800 ft, and 16 at 25,000 ft) for up to 4 h. All breathed 100% oxygen beginning with ascent. Subjects were monitored for precordial venous gas emboli (VGE) and DCS symptoms. Probit curves representing altitude versus incidence of DCS symptoms and VGE allowed estimation of respective risk. RESULTS. VGE were first observed at 15,000 ft with increasing incidence at higher altitudes; over 50% at 21,200 ft and at least 70% at 22,500 ft and above. DCS symptoms were first reported at 21,200 ft with an incidence of 5%. At 22,500 ft, the DCS incidence climbed to 60%. CONCLUSION. The 5% threshold for zero-preoxygenation altitude DCS symptoms is at 21,000 ft and an abrupt increase in DCS symptom incidence with increased altitude."

Effect of Inflight Denitrogenation on Altitude DCS

Scientific monitoring and writing, and technical support activities were provided for the protocol "Effect of Inflight Denitrogenation on Altitude DCS" (AL ACHE #87-30, addendum, 27Mar90; addendum #2, 15Jul91). This study was designed to test the feasibility of prebreathing at altitude and involved various combinations of prebreathe time and altitude. Sixty-eight 68 subject-exposures were accomplished.

Research reports (DIN A005, DIN A009, DIN A010, and/or DIN A016) from this protocol include:

O'Connor RB, Olson RM, Pilmanis AA, Oakley CJ. Decompression sickness (DCS) and venous gas emboli (VGE) with repeated high altitude exposures. (Abstract) Aviat. Space Environ. Med. 1994;65:454.

Abstract: "INTRODUCTION. Repetitive exposures have been implicated as a predisposing factor for increased altitude DCS susceptibility. Additionally, implicit in some administrative procedures is the assumption of a progressive detrimental effect with repeated cases of DCS. Using information from a research database, this study examined changes in DCS and VGE development with repeated altitude exposures. METHODS. Fifteen male subjects underwent eight exposures each to a simulated altitude of 29,500 feet for a maximum of 4 hrs. Four flights were preceded by 75 min of prebreathing, and 4 by 135 min. Dependent variables were DCS and VGE latency and severity. Latency was defined as time in min to onset of DCS symptoms or VGE. Severity for VGE was a 0-4 scale measured by precordial echoimaging /Doppler. For DCS, it was a 1-10 rating of pain by the subject, and a 1-4 rating by observers of the DCS manifestations. Increased susceptibility was defined as a significant ($p<.05$) decrease in latency or increase in severity over the repeated trials. RESULTS. For the 75 min prebreathing exposures, 100% of the subjects developed VGE and 93% had DCS on at least one exposure. With 135 min prebreathing, 80% had VGE and 73% had DCS at least once. None of the latency or severity parameters exhibited a significant increase in susceptibility. CONCLUSION. There was no evidence to indicate increased susceptibility to DCS with repeated altitude exposures, including after DCS episodes. These data could effect decisions such as returning aircrew to flight status following DCS incidents."

Pilmanis AA, Olson RM, Webb JT. The effect of prebreathing at altitude on decompression sickness (DCS) risk. (Abstract) Aviat. Space Environ. Med. 1994;65:453.

Abstract: "INTRODUCTION. Risk of altitude DCS is routinely reduced by breathing 100% oxygen, "prebreathing" (PB), at ground level (GL) prior to ascent. PB at altitude may be as effective as at GL. This capability of inflight denitrogenation could significantly increase flexibility during high altitude aircraft operations. METHODS. Thirty male subjects were each exposed to 6 different flight profiles in an altitude chamber to 29,500 ft after either 1:15 or 2:15 hrs of breathing 100% O2 at (1) GL, (2) 16,000 ft or (3) 18,000 ft. The subjects performed periodic minimal arm exercises at altitude. At 15 min. intervals, they were monitored for venous gas emboli (VGE) audio/visually with a HP Sonos 1000 Echocardiograph. Flights were terminated at 4 hours, or when subjects reported symptoms of DCS. RESULTS. There were no significant differences in either VGE or DCS incidence between ground level PB profiles and PB profiles at 16,000, or 18,000 ft. However, PB at 18,000 ft vs. GL resulted in significantly (P=0.05) shorter VGE and DCS latencies (lat). CONCLUSIONS. Prebreathing to prevent DCS is as effective at 16,000 ft as at GL, but less effective at 18,000 ft."

100% Oxygen Pressure Suit Environment

Scientific monitoring and writing and technical support was provided for the protocol "Decompression Sickness (DCS) Protection Using a 100% Oxygen Pressure Suit Environment" (AL ACHE #91-19, 10May91; addendum, 6Feb92; formerly USAFSAM ACHE #90-17, 13Nov90). This study was designed to identify the threshold of VGE and, if possible, DCS. Twelve subject-exposures were accomplished.

Research reports (DIN A005, DIN A009, DIN A010, and/or DIN A016) from this protocol include:

Webb JT, Balldin UI, Pilmanis AA. Prevention of decompression sickness in current and future fighter aircraft. Aviat. Space Environ. Med. 1993;64:1048-50.

Abstract: "United States Air Force oxygen regulators set to "NORMAL OXYGEN" deliver up to 60% nitrogen to the pilot at cockpit altitudes of 15,000 to 20,000 ft (4573-6096 m). Research chamber exposures to these altitudes while breathing 50% nitrogen has resulted in high grades of venous gas emboli. Expansion of existing gas emboli following an unplanned decompression to ambient aircraft altitude (e.g. loss of canopy) could result in rapid development of decompression sickness (DCS) symptoms. To reduce this potential problem, regulators in current fighters should be set to "100% OXYGEN" until descent from cruise to increase denitrogenation. The United States' Advanced Tactical Fighter and the European Fighter Aircraft may be designed to cruise above 50,000 ft (15,240 m) where cockpit altitudes exceed 20,000 ft with a 5-psi differential (psid) cockpit pressurization schedule. Increasing cockpit differential pressure to 7 psid while breathing 100% oxygen would greatly reduce the chance of significant emboli formation and the potential for DCS but slightly elevate the risks associated with pulmonary overpressure during rapid decompression."

Webb JT, Pilmanis AA. Breathing gas of 100% oxygen compared with 50% oxygen:50% nitrogen reduces altitude-induced venous gas emboli. Aviat. Space Environ. Med. 1993;64:808-12.

Abstract: "The risk of venous gas emboli (VGE) and decompression sickness (DCS) must be determined before selection of the lowest pressure for an extravehicular activity (EVA) pressure suit which eliminates the requirement for prebreathing. In earlier studies, use of a 50% oxygen:50% nitrogen breathing mixture (50:50 mix) during 139 zero-prebreathe decompressions of male subjects to 8.3-7.8 psia resulted in 51 instances of severe VGE and one case of DCS. Our current study investigated effects of 40 zero-prebreathe decompressions of male subjects to 8.3-6.8 psia for 6 h while breathing 100% oxygen and performing moderate exercise. No DCS symptoms were observed. Severe VGE were not detected at 8.3 psia, but were present during 10%, 20%, and 40% of the exposures at 7.8, 7.3, and 6.8 psia respectively. Zero-prebreathe decompression while breathing 100% oxygen results in significantly lower VGE and DCS risk levels than while breathing a 50:50 mix. Our results show that 7.3 psia EVA pressure suits with 100% oxygen should be safer than 8.3 psia suits with a 50:50 mix."

Decompression Sickness Survey

This research project was reviewed by the AL/ACHE and found qualified for "Exempt Research" status under 32 CFR 219.101. The survey was approved via the Surveys Branch, AFMPC/DPMYMS (210-652-5680; FAX -3926), at the USAF Military Personnel Center, Randolph AFB, TX. (Authority: 10 U.S.C. 8012, Secretary of the Air Force; powers and duties; delegation by; implemented by AFI 36-2601, Air Force Personnel Survey Program. USAF SCN: 94-101). A Power-point presentation was developed summarizing all aspects of this study for use in briefing the USAF Scientific Advisory Board.

The research report (DIN A005 and DIN A010) from this protocol, abstracted below, was also summarized in the organizational publication of the Order of Daedalians[7]:

Webb JT, Pilmanis AA. A survey of Daedalian pilots for history of decompression sickness (DCS) from exposure to 20,000 to 25,000 feet: Relevance to future flight operations. 34th Annual SAFE Symposium Proceedings. 1996. 1996;405-411.

Abstract: "The cabin altitude range of 20,000-25,000 ft is important because it has been, and continues to be, frequented during operational missions. Recent research has demonstrated an altitude threshold for zero-preoxygenation DCS symptoms of approximately 21,000 ft in less than three hours. Current USAF directives allow unlimited exposure to 25,000 ft without preoxygenation. Future operation of the F-22 and the Eurofighter 2000 will likely involve sustained cruise at altitudes approximating 60,000 ft. With a 5-psid pressurization system, the pilots of such aircraft will be exposed to a cabin altitude of approximately 22,500 ft. The crews of current and future unpressurized aircraft (e.g., T-37s, AC-130H gunships, CV-22s) also are/will

[7] Webb JT (C Bellion, ed.). Daedalian high altitude survey complete. Daedalus Flyer. Winter, 1996.

be exposed to this altitude range. In addition, pressurized aircraft which must depressurize to accomplish their mission expose large numbers of personnel to these altitudes (e.g., AC-130U gunships for weapons firing, and C-141 and C-130 transports during airdrop operations). A survey of members of the Order of Daedalians (Fraternity of Military Pilots) was conducted because many of these pilots flew aircraft which exposed them to 20,000-25,000 ft on a routine basis. A vast diversity of flying experience was reported by these pilots, and few (<10%) stated hesitation to report symptoms at the time they were observed. Some of the pilots reported using preventive measures, such as breathing 100% oxygen throughout the flight. Overall, 38% experienced DCS symptoms below 25,000 ft. Their responses and candid comments are relevant to current and future aircrews."

12. MOLECULAR SIEVE TECHNOLOGY

The contractor shall perform laboratory procedures such as weighing samples and recording temperature and pressure data. The contractor shall collect product gas samples from molecular sieve oxygen generating systems, and analyze these samples using gas chromatography and mass spectrometry. The contractor shall analyze the molecular sieve for contamination from hydrocarbons, and perform RDT&E to increase sieve efficiency. (DIN A003, A011)

Accomplishments

A contaminant study for the 99% purity molecular sieve oxygen concentrator (MSOC) was conducted. Data were collected while the contaminant was mixed with the MSOC inlet air, while maintaining the MSOC product gas flow-rate of fifteen standard liters per minute (slpm). Contaminants used were carbon monoxide (CO), Freon-12, methane and propane. The range of contaminant concentration in the inlet air was varied from 10 to 4000 parts per million by volume. To investigate the behavior of the MSOC under a low flow condition, the product flow was reduced to one SLPM and the inlet contaminant concentration range was repeated.

At one point, the contaminant study had been temporarily halted pending receipt of a new shipment of contaminant gases. As the study continued, an issue arose regarding the use of ozone depleting substances. Because Freon-12 is such a substance, it was decided that it would no longer be used as a contaminant for the study. Investigators evaluated other contaminants based on polarity and kinetic diameter for substitution of Freon-12. None were identified. Utilizing the initial Freon-12 data, and the data from the other contaminants, it was found that the MSOC was successful in blocking all of the constituents. Analysis of the data indicated that the high performance MSOC with enhanced pressure-swing adsorption (PSA) technology effectively removes carbon monoxide, Freon-12, methane and propane from the inlet air stream more effectively than an MSOC utilizing standard PSA technology.

Evaluation of oxygen concentrators, sensors and monitors used in oxygen systems were routinely performed. System performance data were collected, analyzed, interpreted and reported. Test equipment, methodologies, procedures and data acquisition hardware and software were developed to retrieve data, for the B-1B instrumented OBOGS flight evaluation study at Dyess

AFB, to monitor and control the Hybrid Oxygen System (HOS), to test oxygen monitors at various simulated altitudes and temperatures, and to support the man-rating efforts of the F-16, F-22 and JPATS oxygen systems.

Efforts were also expended under this task in designing, developing and shipping a Molecular Sieve Bed Activity Tester. The tester allows On Board Oxygen Generation Systems (OBOGS) maintenance personnel to evaluate the performance of molecular sieve beds intact (i.e. the bed need not be disassembled to determine if the sieve is still active). As a result of work completed during this effort, novel ideas to improve the performance of an MSOC and it's independence of two sources for operation were spawned for future investigation. (e.g. reference Sections 26.2, .9, & .14).

Lastly, several papers and presentations were generated during this effort. Research reports (DIN A005, DIN A009, DIN A010, and/or DIN A016) include:

Miller GW. Requalification of the B-1B Molecular Sieve Oxygen Generating System with OXYSIV-5 Zeolite Molecular Sieve. SAFE J. 1994;24:25-36.

Abstract: "The B-1B Molecular Sieve Oxygen Generating System (MSOGS) was man-rated by the USAF School of Aerospace Medicine in 1987. In 1992 the molecular sieve manufacturer discontinued production of the original molecular sieve, MG3, and suggested that the Air Force change to a new molecular sieve called OXYSIV-5. The goal of this effort was to requalify the B-1B MSOGS with this new zeolite molecular sieve. Requalification was necessary required to ensure that the system still met the B-1B minimum oxygen specifications. The MSOGS was operated at several simulated cabin and aircraft altitudes, bleed air inlet pressures and temperatures, and product gas flow rates. Unmanned flight qualification tests were conducted at simulated altitudes up to and slightly above the system maximum design altitude of 42,000 feet. Human performance tests were conducted at cabin altitudes up to 25,000 feet. The performance of the MSOGS with OXYSIV-5 molecular sieve surpassed the original system's performance. Hence, the system passed the requalification testing. Product oxygen concentrations at nominal and "worst case" operating conditions appear higher than desirable. Therefore, the addition of an oxygen sensor and a method for controlling the oxygen concentration is recommended."

Miller GW, Fenner JE. Flight Qualification of the B-1B Molecular Sieve Oxygen Generating System with Immobilized OXYSIV-5 Molecular Sieve. 32nd Annual SAFE Symposium Proceedings. 1994;75-81.

Abstract: "The U.S. Air Force (USAF) is considering molecular sieve immobilization as a means to extend the operational life of the B-1B Molecular Sieve Oxygen Generating System (MSOGS). The immobilization process uses a polymer to bind together the molecular sieve pellets to prevent their attrition or fracture. The goal of this effort was to flight qualify a B-1B MSOGS with immobilized OXYSIV-5 molecular sieve. The flight qualification was required to ensure the modified system still met the B-1B oxygen specification. Engineering qualification testing was conducted up to and slightly above the system maximum design aircraft altitude of 42,000 feet. The data collected in this study were compared with qualification data from a previous study with

non-immobilized OXYSIV-5 molecular sieve. Human performance testing was conducted up to a simulated cabin altitude of 25,000 feet. The B-1B MSOGS system with immobilized OXYSIV-5 molecular sieve passed flight qualification testing. The oxygen concentrations delivered by the system with immobilized molecular sieve exceeded the B-1B minimum oxygen specification. However, the performance of the immobilized system at nominal operating conditions was generally below the performance for the non-immobilized system."

Shakocius AM, Miller GW. Methane Challenge of a High Performance Molecular Sieve Oxygen Concentrator. 31st Annual SAFE Symposium Proceedings. 1994;184-9.

Abstract: "The purpose of this work was to determine the ability of a high performance molecular sieve oxygen concentrator (MSOC) to remove methane while operating at high oxygen purity levels. This work was accomplished using a laboratory scale, four-bed, high performance MSOC (U.S. patent #4,880,443) which consisted of two primary beds containing OXYSIV-5 zeolite molecular sieve and two secondary beds containing Takeda 3A carbon molecular sieve. The concentrator operated at an inlet air pressure of 45 psia, a cycle time of 14 seconds, and a product flow rate of one standard liter per minute. Methane was injected into the MSOC inlet gas stream at levels up to approximately 5000 parts per million by volume (ppmv). Contaminant levels were allowed to reach steady-state and measured in the MSOC inlet, product, and exhaust gases with a Beckman, model 402 hydrocarbon analyzer. The experimental results indicate the contaminant introduced into the MSOC inlet gas was separated and carried out with the exhaust gas. The injected methane was not detected in the product gas. The results indicate the high performance MSOC may be more capable of removing contaminants from the inlet gas stream than standard MSOCs, i.e., those containing only zeolite molecular sieve. Further experimental work with other contaminants is planned."

Shakocius AM, Miller GW. A Hollow-Fiber Permeable Membrane Oxygen Sensor for Molecular Sieve Oxygen Generating Systems (MSOGS). 30th Annual SAFE Symposium Proceedings. 1993:94-101.

Abstract: "The purpose of this work was to develop a new oxygen sensing concept that possessed characteristics such as high reliability, low long term drift, long operating life, and very low maintenance. A permeable membrane oxygen sensing device was developed (U.S. Patent No. 5,101,656) that possessed many advantages which may make it suitable for use on-board aircraft, and was capable of measuring the oxygen concentration of a gas mixture composed primarily of oxygen, nitrogen, and argon. Oxygen concentration was determined by measurement of the shell-side flow through a hollow-fiber permeable membrane (DX-810 poly-4-methyl-1-pentene) module. A limited amount of data was collected over a temperature range of 288(K to 308(K, and at simulated altitudes ranging from sea level to 40,000 feet. The sensor measured gases containing oxygen concentrations spanning from 20.8% (air) to 99.8%. In general, the experimental results indicate that the sensor module produced a shell-side flow which varied nearly linearly with the inlet gas oxygen concentration, regardless of ambient temperature or altitude. Equations were fitted to the experimental data so that oxygen concentration, in percent, could be directly calculated from the shell-side flow of the membrane module. This effort showed the feasibility of using a hollow-fiber permeable membrane module as an oxygen sensing device."

Shakocius AM, Miller GW, Fenner JE. The effects of simulated altitude on a high performance molecular sieve oxygen concentrator. 32nd Annual SAFE Symposium Proceedings. 1994;42-5.

Abstract: "The purpose of this work was to investigate the effects of simulated aircraft conditions on a high performance molecular sieve oxygen concentrator (HP-MSOC). A laboratory scale, four-bed, HP-MSOC was operated at simulated aircraft altitudes between ground level and 60,000 feet. The concentrator, based on U.S. patent #4,880,443, utilized two primary beds which contained OXYSIV-5 zeolite molecular sieve, and two secondary beds containing Takeda 3A carbon molecular sieve. The concentrator was operated at several cycle times, inlet air pressures, and product flows. Product gas oxygen concentrations were measured with a Perkin-Elmer, Model 1100, Medical Gas Analyzer. Variations in cycle time, inlet pressure, and product flow rate affected the performance of the HP-MSOC. The highest oxygen concentration measured was 99.8%. At ground level the HP-MSOC performed optimally at an inlet pressure of 55 psia and cycle time of 12 seconds. At altitude, maximum performance was achieved at an inlet pressure of 45 psia and a cycle time of 12 seconds. The percentage of oxygen extracted from the inlet air as product gas was approximately 4%. The study showed the HP-MSOC is capable of generating oxygen concentrations above 99% during operation at simulated altitude."

13. SPATIAL DISORIENTATION (SD) COUNTERMEASURES RESEARCH

The contractor shall recommend and perform RDT&E in SD countermeasures in aircrew training methods development and primary flight display symbology optimization. The contractor shall recommend and perform RDT&E in aircrew SD recognition and procedures training on the USAFSAM Advanced Spatial Disorientation Demonstrator (ASDD). The contractor shall recommend, design and accomplish research to evolve a series of SO training protocols which extend and upgrade the educational process through each iteration. The contractor shall consider user feedback, serendipitous discovery, and emerging requirements to improve and extend the content through each iteration. The contractor shall evaluate or validate the various training methodologies evolved and make recommendations for transitioning spatial disorientation training techniques to the operational USAF. The contractor shall perform RDT&E in display symbology, primarily in the Armstrong Laboratory Visual Orientation Laboratory (VOL) to include research in the ASDD. The contractor shall conduct display symbology RDT&E in four areas: head-up display (HUD), head-down display (HDD), helmet-mounted display (HMD), and acoustic orientation instrument (AOI) display. The contractor shall recommend research efforts that progress from primarily HUD symbology refinement and standardization, to HDD optimization, to HMD symbology development with AOI occurring concurrently. The contractor shall provide computer graphics programming support to include development of flight simulation code, generation of background scenes for visual and vestibular orientation experiments, production of visual illusions, programs for display graphics, real time data collection, data analysis, and plotting routines for the generation of test subjects performance. (DIN A003, A011)

Accomplishments

Research reports (DIN A005, DIN A009, DIN A010, and/or DIN A016) from this effort include:

Bisson RU, Neville KJ, Boll PA, French J, Ercoline WR, McDaniel RL, Storm WF. Digital flight data as a measure of pilot performance associated with fatigue from continuous operations during the Persian Gulf conflict. AGARD, Nutrition, Metabolic Disorder and Lifestyle of Aircrew 1993;11 pp.

Abstract: "The results of a field study using the C-141 Digital Flight Data Recorder (DFDR) to evaluate whether fatigue affected piloting precision during the Persian Gulf conflict are described. This is the first time digital flight data form the C-141 was used to evaluate routine aircrew performance. Five C-141 military transport crew were granted scheduling priority to quickly accumulate 150 flight hours in less than 30 days. Fatigue estimates were based upon activity logs, fatigue ratings, oral temperature, and mood surveys. Eighty seconds of the instrument landing systems (ILS) final approach above decision height were isolated from digital flight data downloaded after each flight. Both an average and a standard deviation were calculated for airspeed, heading, vertical velocity, pitch, and roll for each of the 80 second ILS segments. The standard deviations served as estimates of piloting precision and were correlated to fatigue measures. No significant differences in piloting precision categorically attributable to fatigue were found. However, individual examples of decreased precision associated with high fatigue levels were observed. These deviations did not occur with enough regularity to conclude whether fatigue or other factors were the root cause. DFDR data can be a sensitive measure of performance, but the operational setting of Desert Storm did not permit control of important variables in this first time effort. The findings suggest that DFDR assessment of flying precision could be of value in performance. Future studies need to evaluate digital flight data versus other cognitive and psychomotor tasks that are sensitive to changes in performance."

Boll PA, Storm WF, French J, Bisson RU, Armstrong SD, Slater T, Ercoline WR, Mc Daniel RL. C-141 aircrew sleep and fatigue during the Persian Gulf conflict. AGARD, Nutrition, Metabolic Disorder and Lifestyle of Aircrew 1993;13 pp.

Abstract: "Subjective fatigue ratings and sleep logs were collected from pilots flying C-141 strategic airlift missions during Operation Desert Shield and Desert Storm. Descriptive summaries of the data are presented for duty-day, crew rest away from home base, and crew rest at home base. The implications of selected findings are presented as recommendations on management of aircrew work/rest schedules during sustained airlift operations."

DeVilbiss CA, Ercoline WR, Antonio JC. Visual performance with night vision goggles (NVGs) measured in USAF aircrew members. SPIE Proceedings: Helmet and head-mounted displays and symbology design requirements. 1994;2218:64-70.

Abstract: "Visual performance data were obtained from USAF NVG aircrew members after they (1) adjusted the goggle using their usual method of adjustment, (2) used the NVG resolution chart to augment their usual method, and (3) used goggle-adjustment procedures learned in the training

class. Results show that without s standard target or procedures, aircrew members were not able to obtain optimal goggle performance - the average visual performance was 20/53 for the 218 aviators in this study. For the 158 aviators who also used the standard target with their usual procedure, there was a significant improvement (average of 20/47). Finally, significantly better goggle performance (average 20/37) was obtained when 48 aviators adjusted their goggles using procedures learned in the adjustment training class."

DeVilbiss CA, Ercoline WR, Demitry PF. Operationally relevant spatial orientation metric. (Abstract) Aviat. Space Environ. Med. 1995;66:491.

Abstract: "INTRODUCTION. A major component of situational awareness (SA) is the pilot's ability to maintain spatial orientation (SO) while accomplishing other complex flight tasks. While a precise definition of SA is still being derived, the SO component has a concise definition expressed in operational terms of aircraft control and performance parameters. However, these parameters traditionally have been limited in scope by evaluating the flight parameters individually, generally in terms of errors made in maintaining specified flight parameters. This paper presents a methodology to define operationally relevant SO metric that expresses performance of a basic flight maneuver as a composite of SO flight parameters. METHOD. The methodology used for this SO metric incorporated three phases -- metric definition, population norms, and concept validation. The definition of the SO performance metric is expressed as a function of two performance parameters, i.e., vertical velocity and airspeed. Population performance norms were obtained from analysis of flight performance data obtained from 27 Air Force pilots at Edwards AFB CA. Each pilot performed three repetitions of four basic flight maneuvers with varying levels of complexity. The metric concept was validated by comparing the SO metric to results from traditional single parameter error data. RESULTS. Analysis of the SO metric identified significant differences between levels of difficulty among the flight maneuvers. So metric results reveal that on average, pilots were able to maintain vertical velocity and airspeed within the defined performance range for 92% of a flight when they were performing the least complex maneuver and were able to maintain the defined range for 75% of a flight for the most difficult maneuver. CONCLUSIONS. This methodology expands the applicability of laboratory results by expressing results in operational terms rather than statistical terms (e.g., significantly lower RMS). Potential applications for this metric include comparison of SO symbology effectiveness as task difficulty increases; evaluation of SO changes with increasing secondary tasking; and identification of varying cross-check strategies for training purposes."

DeVilbiss CA, Sipes WE. Effect of arc segmented attitude reference symbology on a helmet-mounted display during an unusual attitude recovery task. SPIE Proceedings: Helmet and head-mounted displays and symbology design requirements. 1995;2465:255-262.

Abstract: "In an effort to address some of the fundamental issues that must be considered in any long-range progression from "targeting" to "flight instrument" for any helmet-mounted display (HMD), this study investigated the impact of incorporating an HMD with one of the objective flight performance tasks used in head-up display (HUD) evaluations. The task, an unusual attitude recovery, was adapted to require head movements by having the pilot acquire a target either on- or off-axis prior to initiating a recovery. Experiment One did not include any HMD

orientation symbology and established the increase in reaction time 0.82 seconds for the on-axis condition to 1.35 seconds for the extreme off-axis condition (±90 degrees off-axis with a +30 degree head tilt). Experiment Two included minimal HMD orientation information in half of the trials. In trials where no HMD symbology was presented, initial reaction times significantly increased (i.e., from 1.06 for on-axis to 1.56 seconds for ±80 degrees). In trial where pilots were provided minimal HMD orientation information off-axis, initial reaction times did not significantly increase (i.e., 1.06 on-axis to 1.12 seconds for ±80 degrees)."

Ercoline WR, DeVilbiss CA. Effects on spatial orientation (attitude awareness) when flight path information is incorporated with attitude information. (Abstract) Aviat. Space Environ. Med. 1995;66:492.

Abstract: "INTRODUCTION. Traditional attitude information is represented by the pitch and bank symbology depicted on the head-down display attitude indicator. Flight path, a representation of the total velocity vector of the aircraft, is usually depicted only on the head-up display. Technological advances in display symbology permit the incorporation of flight path information with attitude information, resulting in the integrated display of pitch, flight path, and bank information. A flight path-centered display can now replace the more common pitch-centered attitude indicator. The purpose of this study was to determine if perceptual attitude awareness differences exist between the traditional pitch-centered display and the more novel flight path-centered display. METHOD. The Flight Instrument Development Lab was configured to resemble the proposed flat panel C-141 aircraft head-down display instrument panel. Attitude symbology was presented with two different pitch symbols using both the flight path-centered and the pitch-centered concepts for a total of four displays. Each of twelve rated pilots were asked to recognize ten different attitude conditions and recover according to standard instrument procedures. RESULTS. Differences among the four displays were marginal for the unusual attitude conditions of this study. The flight path-centered display showed significantly faster response times than the pitch-centered display (0.86 seconds versus .95 seconds, $p<.02$), while the ANOVA for correct responses yielded a two-way interaction between the attitude symbol-centered concept and the shape of the pitch symbol. CONCLUSIONS. Although the flight path-centered concept shows promise, it is recommended that the traditional concept of the pitch-centered attitude display continue to be used as the standard for attitude information. Further studies are recommended with a greater cross section of mission requirements (e.g., high angle of attack situations)."

Ercoline WR, Devilbiss CA, Lyons TJ. Trends in USAF spatial disorientation accidents--1958-1992. SPIE Proceedings: Helmet and head-mounted displays and symbology design requirements. 1994;2218:257-260.

Abstract: "Data from published reports of spatial disorientation (SD) and aircraft accident folders over the past three and one-half decades were analyzed. The rate of major aircraft accidents per 100,000 flying hours decreased from 5.36 during the 14-year period of 1958-1971 to a rate of 2.22 during the 21-year period 1972-1992. During the same two time periods, however, the rate of SD-caused major aircraft accidents per 100,000 flight hours remained approximately constant (0.32 and 0.35, respectively). Even though the average number of SD

mishaps decreased from 23 per year in the 1958-1971 period to 12 per year in the 1972-1992 period, the percent of SD accidents increased from an average of 6 percent during the 1958-1971 to an average of 16 percent in 1972-1992. SD accidents still represent a major drain on USAF resources, but the development of HMD technology provides an opportunity to prevent SD in some of the more demanding operational environments."

Ercoline WR, Lyons TJ, Freeman JE. A study of USAF spatial disorientation accidents. (Abstract) Aviat. Space Environ. Med. 1993;64:425.

Abstract: "INTRODUCTION. Spatial disorientation (SD) continues to be a contributing factor to a large proportion of military aircraft accidents. A study was conducted to investigate the numbers of SD mishaps over the past three and one-half decades. METHODS. Information form published reports of SD mishaps, USAF SD accident investigation data bases, and aircraft accident report folders were analyzed. SD mishaps were coded as such when the investigating flight surgeon found disorientation or vertigo as a definite or suspected factor. RESULTS. The rate of SD decreased from 0.35 per 100,000 flying hours in 1958 to 0.18 per 100,000 fling hours in 1991. However, during the same time period, the proportion of accidents caused by SD increased from 6% to 14% of all accidents. The USAF fielded a new accident-investigation reporting form in July 1989, which for the first time specified SD Type I, Type II, and Type III as possible causes of aircraft accidents. Of a total of 91 major accidents that occurred over the 2-year period beginning in October 1989, SD contributed significantly to 13 (14%). Coding of SD on accident investigation reporting forms was not consistent, however, and semantic differences were found among many of the investigators. CONCLUSION. SD represents a major problem in military aviation. But a lack of a consistent or consensus definition of SD has compromised aircraft accident investigation, resulting in inaccurate reporting of the role of SD in accident causation. A definition of SD based on aircraft flight parameters may be required to identify SD mishaps properly."

Ercoline WR, Yauch DW, Previc FH, Holoviak SJ. Advanced Spatial Disorientation Demonstrator "troop trial" results-SD illusions. (Abstract) Aviat. Space Environ. Med. 1996;67:698.

Abstract: "INTRODUCTION. Proper spatial disorientation (SD) training methods have been discussed for many years. Recently, within the last seven years, the USAF has reconsidered the SD training issue from aground-based point of view. Even though the USAF realizes the importance of good inflight SD training, and weaknesses associated with previous ground-based SD training devices, it has supported the development of an Advanced SD Demonstrator (ASDD)--a ground-based trainer that produces sensation and motions similar to those experienced during most flight conditions. This paper addresses the ASDD profiles (the associated forces, motions , and visuals) and the purpose of each demonstration. METHOD. Forty pilot/pilot candidates were asked to evaluate a series of five well documented, universally understood, SD conditions, using a Likert-type rating scale from one to five. These SD conditions, termed SD profiles, were called the Subthreshold Motion, the Dark-Night takeoff, the Graveyard Spin, the Graveyard Spiral, and the Black-Hole Approach. FINDINGS. Subjects experienced erroneous senses of both magnitude and direction of the control and performance

flight parameters during the SD demonstrations as would be expected during flight. The ASDD produced sensory conflicts not capable of being duplicated with traditional flight simulators. All five illusions received "excellent" overall ratings, with the graveyard spiral reported as having the most variability. Overall, subjects recommended the profiles for use in undergraduate pilot training (UPT)--some were judged as critical to basic flight training. RECOMMENDATIONS. Due to UPT time constraints and consistent, reproducible results, a minimum of three SD profiles per student is recommended for use in the UPT curriculum. Development of the more advanced SD demonstrations, those that could be used during either refresher training or more advanced flight training (e.g., air refueling, formation flight), needs to continue."

Ercoline WR, Yauch DW, Previc FH, Holoviak SJ. Advanced spatial disorientation demonstrator: "troop trial" results. AGARD Conference Proceedings. AGARD-CP-588. 1996;PP2-1-4.

Abstract: "This paper describes five SD illusions designed to determine the capability of the ground-based Advanced Spatial Disorientation Demonstrator (ASDD) to reproduce perceptual effects that normally can be produced satisfactorily only in flight. Although there were many findings during the Troop Trial Study, two appear worth special note. First, the ground-based demonstrations produced realistic motion effects (subthreshold and suprathreshold) about each axis of the gondola. In most cases, visual dominance was achieved. Second, pilot responses to each demonstration were very positive. From the pilot responses alone, this study clearly shows that the application of motion and visual in a device like the ASDD belongs in the flight training programs. Potential of the ASDD is just now being realized."

Ercoline WR, Weinstein LF, DeVilbiss CA, Bitton DF. Attitude information (orange peel) on the head-up display for recovery from unusual attitudes. Proceedings of the 32nd Annual SAFE Symposium, Reno, NV, Oct. 10-12, 1994. 1994;46-51.

Abstract: "Pilots have known for a long time that the head-up display (HUD) is very useful for displaying flight information such as attitude, airspeed and altitude. A primary advantage of presenting this flight information on the HUD is that it reduces the time a pilot must spend head down in the cockpit. Although the HUD provides important flight information, the manner in which the HUD information is presented can often cause confusion during the recognition and recovery phases of unusual attitudes. The "orange peel" concept is a German Air Force design to help the HUD-equipped pilot maintain attitude awareness. This study compares the orange peel concept to the USAF head-up display (HUD) standard for attitude information. Twelve experienced USAF pilots participated in the study. Each subject performed two repetitions of ten unusual attitude recoveries with each of four HUD configurations. HUD configurations included the USAF standard and three variations of the 'orange peel'. The dependent variables were accuracy of initial stick input, the reaction time to the initial stick input, and the reaction time to the initial stick input for correct trials only. No significant differences in performance or subjective evaluation were found among the dependent variables and the four HUD configurations. Subjective data suggest that pilots favor two 'orange peel' configurations over a third. Suggestions are offered for the use of the 'orange peel' concept for HUD attitude information during air-to-air maneuvering and for off-axis helmet-mounted displays."

Holoviak SJ, Yauch DW, Ercoline WR. The USAF advanced spatial disorientation demonstrator program. AGARD Conference Proceedings. AGARD-CP-588 1996;32-1-7.

Abstract: "The search for ground-based devices that can generate realistic motion and forces on an aircraft in flight is ongoing. However, with the maturing of several technologies, mostly in the computer and visual arenas, the Advanced Spatial Disorientation Demonstrator (ASDD) has surfaced as the prime United States Air Force (USAF) candidate. It combines these new technologies to generate repeatable and sustainable flight-like forces with unsurpassed fidelity. The device, though still in its infancy, has proven that realistic spatial disorientation (SD) illusion can be generated in a safe, ground-based environment. This program overview highlights the ASDD's capabilities, which will have a dramatic impact on the way pilots will receive SD familiarization training for the next decade."

Holoviak SJ, Yauch DW, Ercoline WR, Previc FH. Panel: Advanced spatial disorientation demonstrator (ASDD) design, capabilities, evaluation, and trial results. (Abstract) Aviat. Space Environ. Med. 1996;67:697.

Abstract: "INTRODUCTION. Ever since man took to the air in his wonderful flying machines, he has been faced with the hazards and sometimes fatal consequences of Spatial disorientation (SD). Attempts to construct ground-based simulators, trainers or demonstrators of this pilot killer, have met with varying levels of success. over the past decade the ceaseless efforts of one pioneer in the study and research of pilots abilities to cope with SD have resulted in the design and procurement of the latest state-of-the-art ground-based, SD demonstration devices. The brain child of Dr. Kent Gillingham, the Advanced Spatial Disorientation Demonstrator (ASDD) was accepted by the USAF in Sept. 1994. Over the past year the energetic team of USAFSAM/FP and AL/CFTF have formed a cohesive group focused on refining and exploiting the multitude of capabilities of this world class device. Two other countries, Germany and Japan have also purchased similar ASDD devices and have pursued similar tracts of research into the SD problem. This panel will describe the unique capabilities of the USAF ASDD from its seamless 120 degrees visual full color system to its four directions of motion and complex computer systems. It will also discuss the most recent results of troop trials focused at evaluating the utility and efficacy of the ASDD as the next generation of ground-based SD training and research devices. The ultimate goal of the USAF ASDD program is to provide the most realistic ground-based SD training and research device possible. A final portion of the panel will discuss the future objectives for advanced pilot training and potential research to enhance the pilots ability to function in the aerospace environment."

Holoviak SJ, Yauch DW, Ercoline WR, Previc FH. Advanced spatial disorientation demonstrator (ASDD) design and capabilities. (Abstract) Aviat. Space Environ. Med. 1996;67:697.

Abstract: "INTRODUCTION. Spatial disorientation (SD) has been a flight safety problem as long as airplanes have been flown. The USAF alone loses flying assets approximately nearly $90 million a year, a staggering figure that does not even reflect the value of lost lives. Surprisingly, even though we know quite a bit about this pilot killer, SD continues to be one of the most

elusive problems that is extremely difficult to duplicate in a ground-based training device. This portion of the panel describes the latest advances in the design and capabilities of the USAF's newest ground based SD device, the Advanced Spatial Disorientation Demonstrator or ASDD. METHOD. At Brooks AFB, TX, USAFSAM and the Armstrong Lab, under the direction of the Human Systems Center, formed a dedicated team to bring this fantastic training and research device on line. The ASDD is a critical tool in the development of countermeasures against SD. One of only three devices currently up and running throughout the world (Germany and Japan own similar devices), it contains an enviable list of highly desirable features. A wide (120 by 40 degree) visual window, a reconfigurable glass cockpit, and a motion base that moves in 4 independent degrees of freedom, all on an 8 foot planetary arm capable of producing about 2.2 times the force of gravity. The yaw axis and visual system make it different than any other centrifuge or flight simulator in that it combines the desirable features of both. Hence, the device allows us to study and demonstrate the causes of SD as well as develop realistic countermeasure to cope with them. CONCLUSION. The general role of the ASDD is to provide the most realistic, ground-based, spatial disorientation training possible to help prevent SD-related mishaps and to enhance mission performance. The training goal is to have a sophisticated, ground based device that can produce both visual and vestibular illusions that closely resemble those felt in an actual aircraft in flight. It is hoped that this mini-centrifuge type device could enhance the training of pilots in correct procedures to more quickly recognize and cope with SD."

Lessard CS, Maidment G, Previc FH, Self B, Beer J, and Tong A. Visual scene effects on the somatogravic illusion. AL/CF-TR-1997-0141. 1997:30pp and (Abstract) Aviat. Space Environ. Med. 1998;69:[In Press].

Abstract: "The somatogravic illusion is a dangerous illusion that is believed to have caused a large number of mishaps in civilian and military aviation over the years. This illusion is usually experienced during forward acceleration, which creates a backward inertial force that combines with gravity to produce a resultant gravitoinertial vector rotated backward from the pilot; hence, the pilot perceives a pitching-up of the aircraft. The false climb illusion demonstrates the limitations of the otolith organs in providing accurate information to the brain, when there is insufficient visual information to correct the misinformation; hence, the objective of this research was to determine the relative importance of various visual scene cues in achieving visual dominance over nonvisual orientational inputs. The three orientational cues that were presented in both isolation and in various combinations were perspective splay, texture flow, and a horizon line. All of the visual scene cues were designed to depict level flight in the face of a pitch-up somatogravic illusion (SGI). It was hypothesized that some visual cues would be more effective than others in reducing the magnitude of the perceived somatogravic pitch-up illusion when compared to the eyes-closed SGI condition. No significant differences were observed between the perceived pitch during the eyes-closed and any of the other visual conditions. The results suggest that the scenes may have been too basic, not bright enough, or not as realistic as a bright daytime scene."

Lyons TJ, Gillingham KK, Ercoline WR, Freeman JE. Classification problems of U.S. Air Force spatial disorientation accidents, 1989-91. Aviat. Space Environ. Med. 1994;65:147-152.

Abstract: "Spatial disorientation (SD) continues to contribute to a fairly constant proportion of military aircraft accidents. The U.S. Air Force (USAF) fielded a new accident investigation reporting form in July 1989, which for the first time specified Type I SD, Type II SD, and Type III SD as possible causes of aircraft accidents. Of a total of 91 major accidents that occurred over a 2-year period beginning in October 1989, SD was rated as contributing significantly to 13 (14 percent). Coding for SD on accident investigation differed in their approaches to coding accidents as SD-related; other differences were noted between flight surgeons and pilots, and additional procedural differences resulted in inconsistent reporting over time. There is a consensus that SD represents a major problem in military aviation, but a scientific approach to this important problem would be facilitated if agreement could be reached on definitional and semantic issues."

Newman RL, Haworth LA, Kessler GK, Eksuzian DJ, Ercoline WR, Evans RH, Hughes TC, Weinstein LF. TRISTAR 1: Evaluation methods for testing head-up display (HUD) flight symbology. AL-CF-TR-1994-0159. NASA-TM-4665. 1995;88pp.

Abstract: "The first in a series of piloted head-up display (HUD) flight symbology studies (TRISTAR) measuring pilot task performance was conducted at the NASA Ames Research Center by the Tri-Service Flight Symbology Working Group (FSWG). Sponsored by the U.S. Army Aero flight dynamics Directorate, this study served as a focal point for the FSWG to examine HUD test methodology and flight symbology presentations. HUD climb-dive marker dynamics and climb-dive ladder presentations were examined as pilots performed air-to-air (A/A), air-to-ground (A/G), instrument landing system (ILS), and unusual attitude (UA) recover tasks. Symbolic presentations resembled pitch ladder variations used by the U.S. Air Force (USAF), U.S. Navy (USN),and Royal Air Force (RAF). The study was initiated by the FSWG to address HUD flight symbology deficiencies, standardization, issue identification, and test methodologies. It provided the mechanism by which the USAF, USN, RAF, and USA could integrate organizational ideas and reduce differences for comparisons. Specifically it examined flight symbology issues collectively identified by each organization and the use of objective and subjective text methodology and flight tasking proposed by the FSWG."

Poole PE, Ercoline WR DeVilbiss CA, Cornum KG. Spatial Disorientation during high workload and fatigue. (Abstract) Aviat. Space Environ. Med. 1996;67:713.

Abstract: "INTRODUCTION. For years researchers have thought fatigue may be a primary catalyst of spatial disorientation (SD). We understand the flight environment and the physiological and psychological demands placed upon the pilot, but we are at a loss to fully explain the breakdown in the normal chain of events that sometimes cause a mission failure. The reasons a pilot becomes spatially disoriented remain a mystery. This study was designed by the Sustained Operations Branch of the Armstrong Laboratory to examine the effects of fatigue during a typical Desert Storm scenario. Incidents of SD during the flight simulation portion of the study are reported. METHODS. Eleven pilots flew a simulated overseas deployment followed by a series of six employments against hostile aircraft. The complete scenario lasted six full days and replicated actual Desert Storm missions. During the employments, the pilots flew four-ship radar departures, combat air patrol (CAP), air refueling, air-to-air engagements, and instrument

recoveries to single-ship landings. SD metrics included a number of self-reported SD episodes, SD incidents observed by the console operator, and flight performance variations during an instrument approach and landing. The study lasted eight weeks with five of the eleven pilots participating twice for a total of sixteen data runs. RESULTS. Five incidents of recognized SD, primarily the "leans" were reported. During a total of 800 simulated flight hours there were two occasions when a pilot crashed due to loss of spatial orientation. The mishap rate for this simulation far exceeds historical SD mishap rates for this weapon system (i.e., 250 versus .55 per 100,000 flight hours). CONCLUSIONS. The total number of SD episodes was small and not sufficient to indicate a correlation between increasing fatigue and frequency of episodes. Although this study's mishap rate was dramatically higher than actual, SD mishap rates for this weapon system, it should be pointed out that the current SD mishap rate is calculated during non-combat conditions. Even though pilots did not report more episodes of SD as the days progressed, a few pilots were observed to doze during simulated flight segments with lower levels of mental/psychomotor demand (e.g., CAP)."

Previc FH, Breitmeyer BG, Weinstein LF. Discriminability of random-dot stereograms in three-dimensional space. Intl. J. Neurosci. 1995;65:247-53.

Abstract: "The effects of shifting attention to targets in 3-dimensional (3-D) visual space were investigated. The perceptibility of crossed-disparity (near) and uncrossed-disparity (far) targets located in the upper-left, upper-right, lower-left, and lower-right visual quadrants was measured during attention shifts that were directed by means of centrally presented arrows to the left or right, upper or lower, and near or far fields. Although left-right attention cues produced the expected perceptibility benefits, upper-lower cues produced no benefits and near-far ones produced attentional costs. The effect of shifting attention along the up-down axis using peripheral cues was also investigated; in this case, significant benefits were obtained, especially in the upper visual field. These results and those from basic detectability experiments point to the existence of important inhomogeneities in perceiving and attending to targets in 3-D visual space."

Previc FH, Ercoline WR. Ground-based spatial disorientation training in the USAF: past and current devices. Proceedings of the Eighth International Symposium on Aviation Psychology 1995;1318-1322.

Abstract: "This paper focuses on the historical improvements on SD training devices in the USAF and, to a lesser extent, other civilian and military organizations from the 1920s to the present. The planned role of the USAF's state-of-the-art SD training device--the Advanced Spatial Disorientation Demonstrator (ASDD)--in future ground-based SD training for undergraduate and graduate pilots will be highlighted."

Previc FH, Yauch DW, DeVilbiss CA, Ercoline WR, Sipes WE. In defense of traditional views of spatial disorientation and loss of situation awareness: A reply to Navathe and Singh's "An operational definition of spatial disorientation". Aviat. Space Environ. Med. 1995;66:1103-6.

Abstract: "In a recent article in Aviation, Space, and Environmental Medicine, Navathe and Singh proposed new "operational" definitions for spatial disorientation (SD) and loss of situation(al) awareness (LSA). The major feature of their new scheme was to treat the two phenomena as distinct, with SD attributable to physiologically based (peripheral) illusions and LSA to psychological (central) factors. The present commentary argues in favor of traditional views of SD that consider spatial orientation to be a subset of overall situation awareness."

Previc FH, Yauch DW, Ercoline WR, Holoviak SJ. Evaluation of the advanced Spatial disorientaion demonstrator visual system. (Abstract) Aviat. Space Environ. Med. 1996;67:698.

Abstract: "INTRODUCTION. One of the novel features of the Advanced Spatial Disorientation Demonstrator (ASDD) is its wide-field-of-view (120-deg), infinity-optics visual system. Its visual system was assessed as part of a general ASDD evaluation study. METHODS: The ASDD visual system was evaluated in terms of three major criteria: objective performance, subjective ratings of it by the 40 pilots involved in the ASDD evaluation study, and its ability to achieve "visual dominance". RESULTS. The resolution limit of the ASDD visual system (6-min. of arc) was shown to match the pixel resolution of the graphics computer; however, the maximum contrast that could be achieved for low-spatial-frequency ratings was only (50% in the center of the screen. Scenes were updated at 30 Hz of less, and there was considerable optical distortion in the periphery. The ASDD visual system overall was rated as "good" by pilots; the "seamlessness" (continuous visual field) and size of the ASDD visual display received the most favorable individual ratings whereas the most frequent negative comments concerned its image quality (e.g., "blurry" and "hazy"). Overall pilots rated the value of the visual scenes and illusions as "very-to-critically" beneficial to their spatial disorientation training. The ASDD visual scenes were shown generally to dominate orientation judgments in four of five SD illusions presented to the pilots in which the nonvisual inputs were nonexistent, weak, of ambiguous. In a fifth illusion that was later modified, the ASDD visual scene proved only partly successful in overcoming clearly discrepant nonvisual tilt sensations by means of a false visual horizon (sloping cloud deck). CONCLUSION. The ASDD visual system appears fundamentally sound in its basic design and can adequately simulate the action of the real visual world inmost SD situation. However, it is essential to improve its image quality, reduce its peripheral distortion, and increase its overall computer graphics capability to meet the future SD ground-based training needs of the USAF."

Sagi-Dolev AM, Werchan P, Antebi A, Lessard CS. Centrifuge and flight evaluations of the IMOD GLOC sensor helmet. (Abstract) Aviat. Space Environ. Med. 1998;69:[In Press]

Abstract: "INTRODUCTION. A prototype was developed to demonstrate technological feasibility of real-time electropysiologically based GLOC detection in the advanced fighter cockpit Development included an EEG/EOG/EMG based GLOC algorithm for detection within 2 seconds of occurrence, and a Helmet Mounted Electrophysiology Sensing System (HM-ESS). Components are mounted in the custom fit f-16 flight helmets in accordance with operational and ejection safety criteria. This presentation will discuss the design concepts and evaluation studies of the helmet thus far conducted at the centrifuge at Brooks AFB, Zlin and F-16 flight testing in

Israel. METHODS. Centrifuge: 5 subjects were fitted custom fit Israeli F-16 flight helmets with HM-ESS. Dry electrode channels were compared with wet electrodes for frontal EEG and EOG leads. Protocol included baselines, High G and ACSM profiles. Zlin and F-16 Flights: Dry leads were acquired during a 45 minute flight including high, negative and alternating G profiles. For all studies % of spectral power for each second of event at each frequency in the range of 1-30Hz was evaluated in correlation with time based wave morphology, synchronized G values, event marks, tri-axle head movements and video close-ups of centrifuge/flight subjects. RESULTS. Baseline data showed correlation of wet and dry EEG. Centrifuge studies showed increase in low frequency 1-3Hz activity in dry vs. wet studies, we found this to be primarily correlated with dry electrode location over forehead, motion artifact, eye and facial movements. Two helmets saturated under G loading due to capacitor pressure in the dry EEG preamp. Flight test results of baseline data showed correlative results in standard EEG bands. During G loading increased power in low frequency bands were lower then centrifuge tests but still apparent for 1-3Hz. Eye blink "editing" decreased this significantly. Increases in EMG power (>15Hz) was correlative to G loading and straining as predicted. CONCLUSIONS. It is technologically feasible to acquire frontal EEG/EOG/EMG in high performance air craft. Artifacts in low frequency bands are primarily due to human artifacts, heart rate, pulsation, movement and most significantly eye movements. Artifact reduction algorithms for increased robustness is the primary point for further corrective development. EMI/RFI does not pose a problem in our cockpit. This system can potentially be used for any operational MMI application requiring frontal EEG/EOG/EMG data."

Sipes WE, DeVilbiss CA, Yauch DW. Situational awareness is greater than the sum of its parts. In: Situational Awareness in the Tactical Air Environment: Augmented Proceedings of the Naval Air Warfare Center's First Annual Symposium. (AW Schopper, Ed.). 445pp. 1996;49-61.

Abstract: "In 1992, in response to the Chief of Staff of the U.S. Air Force requesting a major study of situational awareness (SA), a Situational Awareness Integration Research Team (SAINT) developed a working definition which was endorsed by the Deputy Chief of Plans and Operations: "A pilot's continuous perception of self and aircraft in relation to the dynamic environment of flight , threats, and mission, and the capability to forecast, then execute tasks based on the perception." To study SA, we use cognitive psychology, focusing on reasoning and the mental processing of information like perception, memory, language, and problem solving. Situational awareness is not just adding the many parts together. We learn from Gestalt psychology the concept of "the whole is greater than the sum of the parts." This presentation will evaluate SA in terms of environments of tactical SA, six elements or individual traits necessary for good SA, seven areas endorsed by 173 operational F-15 pilots, SA management strategies used by novice and expert pilots, and an emphasis on spatial disorientation (SO) as one of the most critical components of SA."

Thomas SR, Ercoline WR, Poe D, Graham MR, Patterson JA, McLin LN. The effects of laser eye protection devices (LEPDs) on simulated and actual F-15E cockpit visibility. 30th Annual SAFE Symposium Proceedings. 1992;45-57.

Abstract: "The effects of wearing laser eye protection devices (LEPDs) on the visibility and color appearances of simulated and actual F-15E cockpit displays were determined. Two laboratory experiments were performed to test the compatibility of three LEPDs with simulated F-15E head-down displays (HDDs). Two field investigations using the F-15E Weapons Systems Trainer (WST) and tow ground tests with the F-15E aircraft were performed to test compatibility of the FV-6Minus Ruby (FV-6MR) and FV-7 LEPDs with F-15E cockpit lighting. Laboratory experimental results indicated that LEPD use significantly affected the readability and color appearances of HDD symbology, but these effects were highly dependent on the size and color of the symbology. LEPD use did not significantly affect aircrew members' ability to identify low-level flight symbology or terrain colors on tactical pilotage charts; however, some terrain color contours were missed more frequently than others. The results of the F-15E WST and ground tests indicated that the majority (92.3%) of the aircrew members rated FV-6MR LEPDs safe for nighttime air operations, and all of the aircrew members rated the FV-7 safe for daytime air operations. The visibility of two navigational displays on the color HDD were affected by wearing the LEPDs. Suggestions for improving the compatibility of these displays with LEPDs are offered. Flight testing is recommended to obtain additional information about LEPD cockpit and mission compatibility."

Thomas SR, Ercoline WR, Weinstein LF, Saflarski E, Cartledge RM. A preliminary field investigation on the visibility of head-up display symbology through laser eye protection devices. 30th Annual SAFE Symposium Proceedings. Las Vegas, NV, Nov. 2-4. 1992;37-44.

Abstract: "The effects of wearing laser eye protection devices (LEPDs) on the visibility of HUD symbology were evaluated using a T-38 aircraft equipped with an F-16 HUD. Eight pilots rated the visibility of HUD flight symbology under six viewing conditions using a seven-point scale. The no-visor daylight (NV-day), USAF sun visor (SV), and FV-7 LEPD (FV-7) viewing conditions were performed under daylight conditions, and the no-visor nighttime (NVnight), FV-6 LEPD (FV-6), and FV-6 Minus Ruby LEPD (FV-6MR) viewing conditions were performed under simulated nighttime conditions. The mean ratings for all conditions were between 6 and 7, indicating that the HUD symbology was visible under all viewing conditions. Pilots commented that wearing the FV-6 and FV-6MR LEPDs reduced 'blooming' of the symbology and improved visibility. Flight testing should be conducted before final conclusions can be drawn regarding HUD symbology visibility through LEPDs."

Veronneau SJH, Ercoline WR, Yauch DW. Perceived pitch versus actual pitch-a fatal case of pilot perceived attitude determining altitude. (Abstract) Aviat. Space Environ. Med. 1996;67:714.

Abstract: "INTRODUCTION. Little recent attention has been placed on spatial disorientation (SD) aspects in commercial aviation although more than a dozen air transport crashes reported on many years ago were believed to be a result of the somatogravic illusion. This paper discusses the forces that create the somatogravic illusion when a pilot executes a takeoff or missed approach, and the investigation of the events leading to a fatal commercial accident involving this illusion. METHODS. Flight data from an air transport crash were reviewed by the authors and correlated with pilot control inputs. The individual gravitoinertial force vectors acting along the longitudinal

axis (G_x) and the vertical axis (G_z) were summed to produce the net gravitoinertial force (G) acting on the pilots. Perceived angles of pitch were calculated and compared to actual pitch from the digital flight data recorder. RESULTS. The missed approach was conducted close to the decision height for the instrument landing system, shortly after encountering instrument meteorological conditions (IMC) in a severe windshear/microburst with very heavy rain. The longitudinal gravitoinertial force which helped produce the false pitch sensation was a combination for the acceleration of the jet for the aborted landing and adverse weather. A net change between the actual pitch and the perceived pitch varied from no difference during the 150' initial climb in the go-around to a maximum of 19 degrees seconds before ground impact. The nonflying pilot (PIC) ordered the flying pilot to lower the aircraft nose. During the missed approach attempt the aircraft entered a descent and impacted the ground. Prior to impact the crew came out of the precipitation and saw trees in the flight path. CONCLUSIONS. The somatogravic illusion should be thought of as a potential threat to any aspect of aircraft flight. In this mishap a loss of situational awareness is documented in just about every aspect of the approach and go-around. As a scenario for cockpit resource management training this mishap illustrates the need for aircrew to be aware of how SD can affect team members separately and how in IMC and curing critical phases of flight it can interfere with crew coordination. SD demonstrations and training, if made part of pilot human factors training and refresher programs, could enhance crew coordination and better prepare pilots to cope with SD."

Weinstein L, Ercoline W, McKenzie I, Bitton D, Gillingham K. The standardization of aircraft control and performance symbology on the USAF head-up display. AL/CF-TR-1993-0088. 1993;81pp.

Abstract: "Researchers and pilots throughout the world continue to examine and debate the utility of the head-up display (HUD) for presenting instrument flight information. Although initially intended for the presentation of landing and weapons delivery information, the HUD has evolved into a flight instrument that researchers and pilots claim is successfully replacing many of the traditional panel instruments. Since the Attitude Awareness Workshop of 1985, the United States Air Force (USAF) has conducted numerous research projects to determine the most effective way to integrate the HUD with the other mission-essential instrument displays. The requirement to use the HUD for instrument flight, as well as a need to determine the optimal configuration of the HUD symbols, prompted a significant portion of that research. This paper summarizes the research efforts conducted by scientists in the Visual Orientation Laboratory (VOL) and the Flight Motion Effects Branch of the Armstrong Laboratory (AL/CFTF). Suggested standardization guidelines based on empirical findings are discussed, including the use of: counter-pointers for airspeed and altitude indicators, vertical and horizontal asymmetry for pitch-ladder configurations, a ghost horizon, analog information for vertical velocity, energy management symbology, and quickening for climb/dive markers."

Weinstein L, Gillingham K, Ercoline W. United States Air Force head-up display control and performance symbology evaluations. Aviat. Space Environ. Med. 1994;65:A20-30.

Abstract: "The United States Air Force has conducted an extensive research effort to determine the most effective way to present aircraft control, performance, and navigation information on the

head-up display (HUD). The primary objective of the research was to develop a standard HUD symbology set to be used as a primary flight reference for fighter-type aircraft during instrument meteorological conditions. This paper summarizes the research conducted by scientists in the Visual Orientation Laboratory (VOL) at the Flight Motion Effects Branch of Human Systems Center's (HSC) Armstrong Laboratory. Five experiments that examined various control and performance symbology elements are reviewed. Suggested standardization guidelines based on experimental findings are discussed, including: the use of counter-pointers for airspeed and altitude indicators, vertical and horizontal asymmetry for climb/dive ladder configurations, a ghost horizon, analog vertical-velocity information, energy management symbology, and quickening for climb/dive markers."

Weinstein LF, Ercoline WR. The standardization of USAF head-up display symbology. 30th Annual SAFE Symposium Proceedings, Las Vegas, NV, Nov. 2-4, 1992. 1993;106-108.

Abstract: "The USAF's task of optimally configuring a standard symbology set for HUDs encompasses full-time attitude, altitude, and airspeed data, immediately discernible attitude-recognition, unusual-attitude recovery capability, and complete fault indication. Many of the symbols and concepts used in developing the standardized HUD were adopted from existing symbology sets. An account is given of projects undertaken to address unresolved issues."

Weinstein LF, Ercoline WR. Procedures and metrics for aircraft cockpit display evaluations. Proceedings of the 37th Annual Meeting of the Human Factors and Ergonomics Society. Seattle, WA, Oct. 11-15, 1993. 1993;2:1201-1205.

Abstract: "The standardization of test methods for the evaluation of aircraft cockpit displays is an area display designers need to investigate. Comparable simulation facilities and experimental protocols including tasks, performance parameters, data analysis techniques, and subject pools, need to be employed across military and civilian research laboratories to ensure that the results of simulation efforts are interpreted similarly by all researchers and designers. This paper reviews the types of tasks and data collection, reduction, and analysis techniques used by researchers during a five-year Air Force research program designed to: (1) develop a standard head-up display (HUD) symbology set for use as a primary flight reference during instrument flight and (2) develop a standard symbology set to be used as a baseline for comparing other HUDs. The program objective was met. The symbology set will be included in a revision of Military Standard (MIL STD) 1787, Aircraft Display Symbology."

Weinstein LF, Ercoline WR. Energy management symbology and the standardization of cockpit display symbology. (Abstract) Aviat. Space Environ. Med. 1993;64:464.

Abstract: "INTRODUCTION. The United States Air Force has conducted numerous research projects to determine the optimal configuration for the head-up display (HUD) symbology set to increase spatial orientation and reduce mental workload during instrument flight. One of the research studies that contributed to the standard symbology set examined the optimal format and mechanization for energy management(acceleration and angle of attack) symbology. METHOD. The flight simulation study compared pilots' performance on precision instrument approaches with

four symbology configurations: (1) "E" bracket, (2) "E" bracket with an acceleration caret, (3) dual "C" brackets with acceleration carets, and (4) a worm with an acceleration caret. Performance was evaluated in terms of root mean square deviations from set airspeed, optimum angle of attack, glideslope, and course. RESULTS. There was a statistically significant effect ($p<.05$) on performance due to the configuration of the energy management symbology. Overall, the worm and caret configuration resulted in significantly more accurate performance than did the other three configurations. CONCLUSIONS. The worm and caret energy management symbols were included in the proposed standard HUD symbology set that has been flight validated and will be included in the next iteration of MIL STD 1787, Aircraft Display Symbology."

Weinstein LF, Ercoline, WR, Bitton, DF. The utility of a ghost horizon and climb/dive ladder tapering on a head-up display. AL-TR-1992-0168. Proceedings of the 36th Annual Meeting of the Human Factors Society, Atlanta, GA, Oct. 12-16. 1992;1:48-51.

Abstract: "As part of an Air Force effort to standardize HUD symbology, an unusual attitude recovery task was employed to investigate the utility of a cue, the ghost horizon, that indicates the direction of the actual horizon when the climb/dive ladder horizon line is not within the HUD field of view. Six HUD-experienced and 6 non-HUD-experienced military pilot subjects were used to determine whether there was improvement, with the ghost horizon, in ability to recover from nose-down unusual attitudes in a flight simulator. The ghost horizon was evaluated with 3 different climb/dive ladder line configurations (tapered, non-tapered, reverse tapered). In terms of accuracy of the initial stick input, the ghost-horizon configurations resulted in significantly better performance (about 11 percent better) than did the non-ghost-horizon configurations. The ghost horizon had no effect on initial stick input reaction time or total recovery time. The climb/dive ladder line taper configuration did not affect accuracy, initial stick input reaction time, or total recovery time. Subjective data indicated that the pilots did not have a strong preference for any of the configurations. These findings suggest that the ghost horizon is a useful aid to unusual attitude recovery performance, and may reduce spatial disorientation."

Yauch DW, Ercoline WR, Previc FH, Holoviak SJ. Advanced spatial disorientation demonstrator: Component, profile, and training evaluation. AGARD Conference Proceedings 588. AGARD-CP-588. 1996;28-1-5.

Abstract: "Results of the first experimental evaluation of the Advanced Spatial Disorientation Demonstrator (ASDD) installed at Brooks AFB, TX are described. The ASDD was evaluated by a mix of experienced pilots and novices. Spatial Disorientation (SD) training profiles were programmed into the device in an attempt to induce Type I (unrecognized) and Type II (recognized) SD. Reliable generation of SD illusions and Visual/vestibular sensory conflicts on the ground in a safe environment, can in principle provide training to aircrew to aid in recognizing and coping with SD in flight, and also can be used as an environment to design instrument displays. To that end, the ASDD components, SD profiles, and training were evaluated."

Yauch DW, Ercoline WR, Previc FH, Holoviak SJ. Advanced spatial disorientation demonstrator: component, profiles, and training evaluation. (Abstract) Aviat. Space Environ. Med. 1996;67:698.

Abstract: "INTRODUCTION. On 30 September 1994, the USAF accepted the Advanced Spatial Disorientation (SD) Demonstrator (ASDD) from the manufacturer. Five SD profiles were developed and programmed along with the visual programming required to complete the sensory environment. This paper reports the findings form the evaluation the ASDD components, the profiles themselves, and the training value of the profiles. METHOD. Forty pilots/pilot candidates were asked to subjectively evaluate the ASDD's components, profiles, and training value. The ASDD in-cockpit session was broken into two phases: a free-fly phase (35 min) and a profile phase (35 min). During the free-fly phase, subjects were asked to evaluate the visual display, instrument panel, controls, and cockpit environment via the investigator asking the subject 52 questions regarding characteristics of these ASDD components. The subjects responded on a one to five scale (unsat to excellent) and could provide free-form comments. During the profile phase, subjects rated the profiles for illusion effectiveness and for generating sensory conflicts. the profiles combined visual and vestibular illusions/effects, and were called Subthreshold Movement, Dark-Night Takeoff, Graveyard Spin, Graveyard Spiral, and Black-Hole Approach. FINDINGS. The ASDD components were highly rated, with the visual system rated the lowest (3.73 ±74) due to low depth perception ratings (subject comments indicated fuzzy/blurry images). The profiles were highly rated with Graveyard Spin receiving highest effectiveness conflict ratings (4.93 ±26/4.80 ±51). Dark Hole Approach receiving the lowest effectiveness rating (4.60±.62) and Graveyard Spiral receiving lowest conflict rating (4.53 ±1.05). The subjects highly rated the ASDD's aircrew training value, indicating it was greatly superior (4.94 ±24) to prior SD training, and USAF pilots should receive ASDD training every two years (4.03 ±1.13) RECOMMENDATIONS. Development of advanced SD ground device training should continue, with emphasis on developing 'refresher' training profiles for experienced aircrew. As a minimum, ASDDs should be utilized for basic SD training during undergraduate (initial) flying training."

14. SUSTAINED OPERATIONS RESEARCH

The contractor shall provide specialized Human Factors expertise support to the Sustained Operations Branch of AL/CFT in support of high priority Air Force operations. Specific requirements are: (1) to investigate and solve complex human factor issues associated with a person's ability to perform efficiently and effectively in an operational environment; (2) to acquire and develop state-of-the-art objective and subjective methods of measuring individual performance and psychophysiological status; and (3) to apply these measurement methodologies and techniques in a valid evaluation of the effects of aerospace mission demands on aircrew and ground support personnel. The contractor shall conduct analytical and experimental studies in the areas of human factors engineering and experimental psychophysiology to assure data acquisition, statistical procedures, and interpretation of results are consistent with the test design and research protocol. The contractor shall provide on-site technical support to perform laboratory and field evaluation studies for the following specific functional areas: (1) sustained and continuous operations; (2) pharmacological effects on performance; (3) stressful environmental conditions, e.g. hypoxia, gravitation, spatial disorientation; (4) information processing capabilities; (5) performance test battery development; (6) fatigue, work/rest cycles, and circadian rhythms as

they affect ground-and aircrew; and (7) human factors engineering design and specification analysis for weapon systems. (DIN A003, A011)

Accomplishments

Scientific support was provided which related to some of the specific objectives, although the majority of support for this requirement was not initiated. In Subatmospheric Research (Section 11), performance assessment batteries were employed to determine if fatigue was a factor following exercise during preoxygenation before exposures to 30,000 feet for four hours. The potential for developing fatigue is a concern with exercising during preoxygenation prior to decompression. The protocols wherein this work was accomplished were: "Effect of Prebreathe with 100% Oxygen while Exercising on Incidence of Decompression Sickness (DCS)" (AL ACHE #89-25B, addendum, 2Jul92; formerly USAFSAM ACHE #89-25, 15May90) and "Preoxygenation with exercise versus rest: Effect on incidence of decompression sickness (DCS)" (AL ACHE #94-17A; SGO R94-040; approved 30Sep94); PE1 and PE2 respectively. A report (Heaps et al., 1993) showed that the exercises used during PE1 produced moderate lactate levels which began to decline approximately 3 min after the exercise. The PE1 report by Heaps et al. (1993) was based on results from a different set of subjects than used during PE2. However, the exercise equipment and exposure conditions were identical in both studies.

The subjects in PE1[8] completed one Performance Assessment Battery (PAB) immediately prior to beginning preoxygenation and one per h while decompressed. The PAB included two subjective measures of fatigue, the Stanford Sleepiness Scale and a subset of the Moodscale 2, both from the Walter Reed Performance Assessment Battery[9] which were averaged to determine a measure of fatigue at any time during exposure as compared with the morning PAB accomplished prior to any experimental procedures, including preoxygenation. Changes in perceived fatigue were recorded as percentages of the morning PAB average. Only matching results were used; i.e. if a subject remained at altitude for three PABs after one preoxygenation condition and two PABs under another condition, only the first two results at altitude were used to compare those conditions.

Perceived fatigue based on a scale of 0-100% (change from morning PAB) did not exceed 17% at any observation time during any of the exposures. After one hour at simulated altitude, subjects who accomplished the 1-h preoxygenation with exercise showed a significant reduction in fatigue (15.0% to 11.3%; $n=18$; $p<0.05$) which was not evident when the same subjects accomplished the control 1-h resting preoxygenation. The baseline fatigue levels, observed before either preoxygenation, showed that those subjects anticipating 10-min of exercise reported more fatigue than while anticipating the control preoxygenation 15.0% vs 7.9%; $n=18$; $P<.05$). Comparisons of fatigue levels beyond 1 h at altitude revealed no significant differences. No changes in fatigue

[8] See Webb et al. (1996) under Section 11 for additional details about the exposure conditions.

[9] Nesthus TE, Schiflett SG. Monitoring cognitive function and mood with the Automated Neuropsychological Assessment Metrics (ANAM) in decompression sickness (DCS) research. (Abstract) Sixth Annual Workshop on Space Operations, Applications, and Research (SOAR '92). NASA Conference Publication 3187. 1993;II:498.

were observed across time for the exposures preceeded by a 15-min preoxygenation with exercise.

The second protocol (PE2) was incomplete at the end of the contracted effort. The data gathered to date utilizes a critical tracking (dynamic lambda) task from the Walter Reed Battery of tests and preliminary analyses indicate no cumulative fatigue evident after resting and exercising preoxygenation. The lack of increase and low levels of subjective fatigue following preoxygenation with exercise versus resting preoxygenation supports the finding that exercise-induced fatigue is not a factor under these conditions.

Exercise physiologist and exercise technician support was provided for the protocol "Cerebral Metabolism with Moderate External Heating" (AL ACHE #96-10; SGO R9-0; approved). AEWPL provided support in this protocol in collaboration with AL/CFTO and UT Health Sciences Center-San Antonio. The study examined the Q10 effect on cerebral metabolism both overall and regionally. Resting metabolic rate via open-circuit spirometry , blood glucose levels and cerebral blood flow and metabolism via PET scan was measured on subjects pre- and post-heating. Subjects were exposed to a heat stressor via a liquid conditioned garment (similar to the garment worn by astronauts). Subject core temperature was elevated to 38.5°C prior to the post-treatment measurements being made. AEWPL contributions included associate investigator and lab support. Specifically, AEWPL provided expertise in the area of open-circuit spirometry and was responsible for on-site (UTHSC) collection of respiratory gasses and transport of these gasses to BAFB for analysis. Additionally, support was provided for data reduction/analysis/ interpretation and presentation/manuscript preparation.

15. BIOCHEMICAL LABORATORY OPERATION AND SUPPORT

15.1 Biochemistry of G Induced Loss of Consciousness (GLOC)

A small animal centrifuge (SAC) laboratory exists in AL/CFT to study the mechanism of GLOC at the brain cellular level, The SAC consists of two separate laboratories: a physiology laboratory and a biochemistry laboratory. A rodent model has been developed as well as several methods for obtaining biological samples and for the biochemical analysis of these samples. The contractor shall provide a research team of three technicians to conduct experiments in the SAC on a daily basis and analyze the physiological/biochemical results of these experiments. Routine troubleshooting and maintenance of laboratory equipment shall also be accomplished by the contractor. The contractor's team shall develop new techniques to fully understand the problems of GLOC as necessary. All three individuals shall possess a college Bachelor degree or an equivalent in experience. The contractor shall be responsible for the daily operation of the SAC. The contractor shall order and track the usage of all animals required for research. The contractor shall also perform (on a daily basis), required small animal surgery for implanting physiologic instrumentation and provide post-operative animal care as needed. The contractor shall perform all SAC experiments as outlined in the investigators protocol and collect physiological data as required by that protocol. Following centrifuge exposures the contractor shall collect biological samples (fluids and tissues) either by microwave or freeze fixation

techniques. The contractor shall label and document these samples for retrieval by biochemistry lab personnel. The contractor shall post-process and summarize all physiological data on a weekly basis. The contractor shall process all biological samples taken from animals on the SAC. An emphasis will be placed on high performance liquid chromatography system (HPLC) and molecular biology methodology for the analysis of: energy metabolites, glycolytic substrates, hemoglobin, catecholamines, and markers of all stress (c-fos, heat shock proteins, free fatty acid release etc.). Following analysis, data shall be calculated and tabulated. The contractor shall be responsible for coordinating the daily activities of the SAC such that samples are being generated using the centrifuge at a rate consistent with the ability of the biochemistry laboratory to provide analysis of these samples. The contractor shall be responsible for ordering all supplies and equipment necessary to complete the tasks of the SAC. The contractor shall provide technical assistance to either SAC laboratory (physiology or biochemistry) and shall perform routine spectrophotometric analysis of metabolites. The contractor shall be responsible for the final processing of data from the SAC and for providing a graphical representation of completed experiments for report preparation.

Accomplishments

Research reports (DIN A005, DIN A009, DIN A010, and/or DIN A016) from this effort include:

Echon RM, Werchan PM, Sheriff DD, Rogers ME, Caspers MS. Cortical EEG power spectral analysis and 40 Hz oscillations: A quantifiable index for gravitational loss of consciousness. (Abstract) Aviat. Space Environ. Med. 1998;69:[In Press]. [15.1]

Abstract: "INTRODUCTION. Electroencephalography (EEG) remains the single most accessible (non-invasive) and affordable index of cerebral activity. Although EEG is extremely sensitive to changes in cerebral status including sleep and wakefulness, it is limited to the superficial layer of the cortex near the scalp (recording electrodes). In addition, EEG frequency analyses are traditionally performed on changes in only the first 30 frequencies (Hz) using four frequency bands (Delta, Theta, Alpha and Beta). These limitations compounded by artifacts and/or noise associated with high G exposures have prevented a complete understanding of the neurophysiology of G-LOC. Recent findings suggest that higher cognitive functioning is modulated by higher regulators or fast gamma rhythms (oscillations). These gamma oscillations (approximately 40 Hz) increase in amplitude during mental concentration or multitasking and disappear with the loss of consciousness or during anesthesia. These oscillators are not proposed to carry information, but rather to provide a temporal generator for specific neurons that synchronize and/or bind encoded information with other neurons having relevant information and consequently integrating cues from the peripheral environment. METHODS. The effect of acceleration on 40 Hz oscillation was initially characterized on a small animal centrifuge using rats and further validated using the Armstrong Laboratory's human centrifuge. Rats received exposures to nine 30s centrifuge exposures at +2.5G_z increments from +0.5G_z to +25G_z. Intra and interhemispheric differential EEG signals were collected and power spectral components were analyzed using Fast Fourier Transform. RESULTS. Gamma oscillations increased in amplitude (65-350%) immediately post-acceleration onset in rats. These increases remained elevated throughout the duration of acceleration at low (<+10G_z) +G_z exposures. At medium (+10 to

+17.5 G_z) and high (+20G_z to +25G_z) +G_z exposures, elevated oscillations began to disappear at approximately 12-13s post acceleration onset and remained depressed until the offset of centrifugation with an occasional burst in power. In some rats this phenomenon could be observed as early at +10G_z despite continued EEG activities in some other EEG frequency bands. CONCLUSIONS. These data strongly suggest that 40 HZ oscillation could provide a reliable index to quantitate EEG activities relative to consciousness or higher cognitive functioning in rodent models of G-LOC. As human centrifuge testing is typically suspended before an iso-electric EEG signal develops, these findings offer an improved understanding of human consciousness."

Lukatch HS, Echon RM, MacIver MB, Werchan PM. G-force induced alterations in rat EEG activity: a quantitative analysis. Electroencephalography Clin. Neurophysiol. The EEG J. 1997;103:563-573

Abstract: "A major physical limitation affecting pilots is G-force induced loss of consciousness. Previous studies have shown that acceleration produces qualitatively similar effects on human and rat EEG activity. The present study sought to quantitatively correlate changes in rat EEG activity with increasing acceleration levels. A frontal-parietal differential electrode recorded rat EEG data during acceleration exposures (30 s) ranging from +0.5 to +25.0 G-forces G_z. Acceleration levels $\leq 10 + G_z$ had little effect on EEG activity. Acceleration levels of +15 to +20 G_z were associated with increased EEG slowing, depression and sharp waves. Acceleration levels 17.5 +G_z evoked burst suppression followed by isoelectric activity. Times to first onset of delta, depressed and isoelectric EEG activity were approximately 12, 14 and 18 seconds, respectively. Acceleration effects on delta (1 - 4 Hz), theta (5 - 8 Hz), alpha (9 - 12 Hz), beta (13 - 30 Hz) and total (1 - 30 Hz) EEG powers were examined using Fourier transform analysis. EEG measures with the most predictive value at the following post-acceleration onset times (PAOT) were as follows (in seconds): increasing theta power: PAOT 0 - 2, decreasing delta power: PAOT 3 - 9, and decreasing beta power: PAOT $\geq$ 12. This study provides a quantitative description of +G_z-induced alterations in EEG magnitude, time course and spectral content. Additionally, several EEG measures were identified which correlated with acceleration level at specific post-acceleration onset times."

Shahed AR, Barber JA, Galindo Jr. S, Werchan PM. Rat brain glucose and energy metabolites: effect of +G_z (head-to-foot inertial load) exposure in a Small Animal Centrifuge. J. Cereb. Blood Flow Metab. 1995;15:1040-6.

Abstract: "A unique Small Animal Centrifuge (SAC) with online physiological monitoring and brain tissue collection (in <1 s) capability was used to investigate the effect of increasing +G_z levels, exposure duration, number of exposures and time course of metabolic changes in the rat brain. To determine the +G_z tolerance, rats were exposed to +7.5 to +25 G_z (2.5 G increments) for 30 s each and the EEG was monitored. Isoelectric EEG, or loss of consciousness (G-LOC), occurred only at +22.5 and +25 G_z within 14.5 ±3 s. To study the effect of increasing +G_z levels on metabolism, several groups of rats were exposed to either 0.5 (control) or +7.5 to +25 G_z for 30 s. Brains were collected 1 min after the centrifuge run by freeze fixation. A significant increase in lactate ($\geq$(7.5 G_z) and a decrease in glucose, Cr-P, and ATP levels was observed at

≥(15 G_z. Rats were subjected to a single +22.5 G_z exposure for either 15, 30,45 or 60 s to study the effect of +G exposure duration. A six fold increase in lactate and a 75% decrease in glucose was observed following the 60 s exposure. The concentrations of Cr-P and ATP levels decreased significantly after the 15 and 30 s exposures, but no further changes were observed at longer $+G_z$ exposures. The time course of changes in these metabolites was determined by collecting brain samples at 5, 15, 25 or 35 s during or 1, 3, or 15 min after the +25 G_z exposure. A significant decrease in Cr-P occurred within 5 s, but changes in glucose, ATP and lactate required 15 s. The concentration of all metabolites returned to control levels within 3 min, except lactate and adenosine. Lactate returned to control levels and adenosine remained elevated 15 min post $+G_z$ exposure. Exposure of rats to either one, three or five runs at +22.5 G_z (30 s each) resulted in a nine fold increase in lactate and an 87% decrease in glucose 1 min after five exposures. Both Cr-P and ATP decreased after one exposure with no further change after 3 and 5 exposures. These results show that $+G_z$ exposures of short durations cause significant transient metabolic alterations consistent with global cerebral ischemia. We propose that G-LOC (isoelectric EEG) may be an adaptive response by the CNS to excessive $+G_z$-imposed ischemic stress. G-LOC would reduce the overall brain energy demand which, in turn, would reduce anaerobic glycolysis and lactate production."

Shahed AR, Barber JA, Werchan PM. Multiple $+G_z$ exposures cause brain edema in rats. Aviat. Space Environ. Med 1994;65:522-6.

Abstract: "The most serious effect of high sustained $+G_z$ (head-to-foot inertial load) known to occur in pilots of high performance aircraft is$+G_z$-induced loss of consciousness (G-LOC.), which may result in pilot incapacitation and subsequent loss of life. G-LOC is believed to occur due to a critical reduction in cerebral blood flow (CBF). Recently, using a Small Animal Centrifuge (SAC), we showed that $+G_z$ exposure causes global cerebral ischemia in a rodent animal model. Since ischemia, depending upon the severity and duration, has been associated with increased brain water content or edema, the present study was undertaken. Rats were exposed to six exposures of either +5 G_z (30 s each) or + 10 G_z (2 min each) in the SAC at + 20 G_z/s onset rate. The appearance of G-LOC was monitored by the flattening of the electroencephalography (EEG) brain wave recording. G-LOC was observed at 101 ±46 s and 19.2 ±5 s during +10 and +25 G_z exposures, respectively. The brains from these animals were removed 15 min to 24 h after the $+G_z$ exposure and analyzed for edema formation (increase in the percentage of tissue water), metabolites, and cerebral blood volume (CBV). A significant decrease in glucose and an increase in lactate concentration were observed during $+G_z$ exposure. Edema formation was observed 15 min after six exposures of either +10 or +25 G_z. A slight but significant decrease in CBV was also observed in rats exposed to six +10 G_z, long duration, that resulted in G-LOC, can cause cytotoxic brain edema which probably results from tissue hyperosmolality due to metabolic changes and accumulation of lactate during ischemia."

Shahed AR, Barber JA, Werchan PM. Acceleration-induced effects on baboon blood chemistry. Aviat. Space Envron. Med. 1993;64:631-5.

Abstract: "Gravity-induced loss of consciousness (G-LOC) is known to have occurred in pilots since the early 1920's. Most of the research in this area has shown that G-LOC occurs due to a

decrease in cerebral blood pressure and a concomitant reduction in brain perfusion. Since a reduction in cerebral blood flow can cause transient hypoxia, it is important to study the cerebral metabolism during high $+G_z$ exposure. One component of these studies should include measurements of substrate availability and degradative products. In the present study, adult baboons were given multiple high $+G_z$ exposures (2 to 6) using the Armstrong Laboratory human centrifuge. Venous blood was collected by an automatic syringe withdrawal pump before, during and after centrifuge exposures. The concentration of blood gases, glucose and lactate tended to decrease during the centrifuge exposure followed by an increase after the run. Total creatine kinase activity in serum was not significantly altered. These results suggest that during $+G_z$ exposure, anaerobic glycolysis is stimulated resulting in elevated lactate production due to a reduction in cerebral blood flow (CBF). The elevated tissue lactate is released into the central circulation upon resumption of normal CBF (after the termination of centrifuge run). Therefore, the observed decrease in lactate concentration during the run may result from a lag in the release of tissue lactate into the blood due to a reduction in CBF. It is speculated that a high +6 G_z, G-LOC may occur as a protective response to reduce the brain metabolic rate, to maintain energy levels and to prevent severe cellular acidosis. However, further research is needed to establish the relationship between the brain's energy status and the onset of G-LOC."

Shahed AR, Echon RM, Barber JA, Werchan PM. Hyperglycemia delays onset of $+G_z$-induced loss of consciousness (G-LOC) in rats. (Abstract) Aviat. Space Environ. Med. 1994;65:446.

Abstract: "INTRODUCTION. G-LOC in pilots is of great concern for the Air Force and the aeromedical community. Based on our studies using a rodent-centrifuge model, we have shown that G-LOC is a physiological response of the central nervous system to $+G_z$-induced reduction in cerebral blood flow (ischemia). We hypothesized that is the level of energy substrate (glucose) is increased, it may delay the onset of G-LOC. Methods: Two groups of rats, normoglycemic (NG) and hyperglycemic (HG) were subjected to +25 and +10 G_z in the centrifuge until isoelectric EEG (G-LOC) was observed. Brain samples were collected immediately by freeze fixation for the analysis of metabolites. Control rats in each group were subjected to +0.5 G_z. Results: The G-LOC induction time in the HG group (36.33 ±6.4 s) was greater than the NG (12.4 ±0.9 s) group during +25 G_z exposure. During the 6 min, +10 G_z exposure, only 1 or 4 NG, but all five HG rats exhibited G-LOC. Brain glucose levels in the HG group were higher than the NG group at both $+G_z$ levels. During +10 G_z exposure, lactate levels in HG or NG groups were not significantly different from each other. Adenosine triphosphate (ATP) levels ($+25G_z$) decreased ($P<0.05$) in the NG but not in HG group. CONCLUSIONS. This preliminary data suggest that during brief +25 G_z exposure increased glucose, and thus energy (ATP) supply may delay the onset of G-LOC. However, during +10 G_z exposure, we hypothesize, that since brain blood flow is maintained (incomplete ischemia), and due to longer exposure times, higher lactate accumulation in the HG group may trigger G-LOC."

Shahed AR, Echon RM, Werchan PM. Moderate hyperglycemia (HG) increases hypergravic ($+G_z$) tolerance of rats. (Abstract) Soc. Neurosci. 1995;21:514.

Abstract: "INTRODUCTION. We have previously shown that exposure of rats to > $+20G_z$ causes global cerebral ischemia and loss of consciousness (G-LOC) within 15 s. The present

study tests the hypothesis that moderate HG may delay the onset of G-LOC by increasing the level of energy substrate. Methods: Four groups of rats (n=6/gr) were injected (ip) with 1.25 to 7.5g glucose/kg, 30 min before +22.5 G_z exposure in a small animal centrifuge. Two normoglycemic (NG) control groups were exposed to + 0.5 or 22.5 G_z. All rats received two +G_z exposures 15 min apart. G-LOC (isoelectric EEG) and recovery to normal EEG was monitored during centrifugation. Metabolites were measured in the brains collected during the 2nd exposure by freeze fixation 30 s post G-LOC. Results: NG rats exhibited G-LOC at 13.2 ±2 s at +22.5 G_z. In contrast, G-LOC was observed at 68.2 ±50, 65.7 ±35, 32.4 ±14 ($P<0.05$ vs. NG) and 23.4 ±10 s (NS) in HG rats receiving 1.25, 2.5, 5.0 and 7.5 g/kg respectively. Brain and blood glucose were elevated significantly in HG rats. The lactate level increased 4 fold in NG, and 5-7 fold in HG rats at the time of G-LOC. ATP and Cr-P levels were not significantly different compared to NG rats despite longer exposure duration ischemia. DISCUSSION. Moderate HG can increase +G_z-tolerance by delaying the onset of G-LOC. Although HG increased G-LOC-induction time > fivefold, the lactate level increased only two fold over NG, well below the lactate level associated with compromised neurologic outcome following ischemia. We speculate that moderate HG can be useful for increasing +G_z tolerance and preventing G-LOC during brief +G_z exposures."

Shahed AR, Galindo Jr. S, Echon RM, Barber JA, Werchan PM. High +G_z Exposure followed by expression of heat shock protein 70 (HSP70) in rat brain: a RT-PCR study. (Abstract) Soc. Neurosci. 1994;20:1062.

Abstract: "We have previously reported that a 30 s, high +G_z (head-to-foot inertial load) exposure of > +20 G_z causes global cerebral ischemiain rats (Werchan and Shahed, The Physiologist, 35:S143-146, 1992) Also six +25G_z exposures have been shown to cause transient brain edema (Shahed et al. Aviat. Space Environ. Med. 63:5, 1992). In the present study, HSP70 expression was investigated as an early marker of cellular stress. METHODS. Protocol 1: Rats were exposed to +22.5 G_z for either 15, 30 or 60 s in a small animal centrifuge and the brains were collected immediately and 0.5 to 24 h after the run. Control rats were exposed to +0.5 G_z. Protocol 2: Rats were subjected to six 30 s exposures of +22.5 G_z and the brains were collected as in Protocol 1. Total RNA was extracted by RNAzol B method. RT-PCR was performed using 1g of RNA for cDNA synthesis and specific HSP70 primers were used for subsequent amplification. The PCR products (235 bp) were visualized on agarose gels. RESULTS. Expression of HSP70 did not increase above the control level after the 15 or 30 s exposures. Following the 60 s exposure, HSP70 expression increased at 60 and 180 min after the centrifuge run. In protocol 2, the expression of HSP70 increased at 60 and 180 min after the run. DISCUSSION. High +G_z exposure of at least 60 s duration or six exposures of +22.5 G_z were required to increase expression of HSP70. The time points of increased HSP70 expression were similar to those previously reported for brain edema. This suggests that HSP70 expression could be a suitable marker for monitoring post +G_z exposure effects."

Shahed AR, Werchan PM, Stavinoha WB. Differences in acetylcholine but not choline in brain tissue fixed by freeze fixation or microwave heating. Meth. Find. Exp. Clin. Pharmacol. 1996;18:349-51.

Abstract: "Among the many rapidly metabolized compounds in the brain, acetylcholine is one of the most challenging to sample effectively due to its rapid synthesis, degradation and sequestration. To ascertain problems that invalidate sampling procedures, two methods of tissue fixation, microwave heat inactivation and freeze fixation, were used for obtaining mice and rat brain samples, respectively. The data show that acetylcholine levels obtained by microwave fixation were much higher than those obtained by freeze fixation. Choline levels were not affected by the fixation method used. Microwave fixation results in more accurate assessment of acetylcholine levels than the freeze fixation method, even though the tissue fixation time was less than 1 s in both methods, because tissue integrity is maintained in the microwave fixation, but not during freeze fixation."

Werchan PM, Echon RM, Barber JA, Galindo Jr. S, Shahed AR. Estimation of rat cerebral blood flow (CBF) during $+G_z$ centrifuge exposures leading to G-induced loss of consciousness (G-LOC). (Abstract) Soc. Neurosci. 1993;19:1220.

Abstract: "Research is currently in progress using a Small Animal Centrifuge to identify causative factors leading to G-LOC (isoelectric EEG) during short duration high $+G_z$ (head-to-tail inertial load) exposures. Previous measurements of the rat cerebral energy state at the point of G-LOC (10-15 s) are consistent with static bench-top models of global cerebral ischemia (PM Werchan and AR Shahed, The Physiologist, 35 (1); 1992). However, it remains unclear if CBF completely ceases at the point of G-LOC. Four rats were chronically implanted with EEG electrodes and flow probes on the common carotid artery (CA). Rats were given nine consecutive 30 s exposures of +5 to +25 G_z (increments of 2.5 $+G_z$). During all $+G_z$ exposures, CAblood flow (CABF) was significantly reduced (45-100%) within the first 5 sec of onset and completely ceased by the end of the +20 to +25 G_z exposures. G-LOC was observed only during the +22.5 and +25 G_z exposures at 13.6 ±3 sec. Hyperemia was observed within 5 sec after deceleration at all $+G_z$ levels. The magnitude of hyperemia increased as the $+G_z$ level increased up to +17.5 G_z, but was significantly less at higher $+G_z$ levels. It is concluded that a cessation of CABF of sufficient duration is required to elicit G-LOC in rats. Furthermore, the reduction in the magnitude of the hyperemic response at higher $+G_z$ exposures indicates a compromised cardiovascular recovery."

Werchan PM, Echon RM, Shahed AR. Adaptation of rats to chronic high $+G_z$ exposure. (Abstract) Aviat. Space Environ. Med. 1994;65:446.

Abstract: "INTRODUCTION. There is concern in the USAF about potential harmful effects of repeated high $+G_z$ exposure in pilots of high performance aircraft. A study was performed using rats to identify organs/systems affected by frequently repeated G exposure. Methods: A protocol consisting of 4 groups of rats was completed using the AL Small Animal Centrifuge (SAC) equipped with a multi-rat restraint system. The first three groups wee returned to the SAC daily for six weeks and received either three +0.5 G_z exposures, three +22.5 G_z exposures, or one +22.5 G_z exposure/day. One naive size/age matched control rat was paired with animals from group 2 on a daily basis. After six weeks, all rats were sacrificed and samples of blood, brain, adrenal gland, kidney, liver, heart and bone were removed for analysis. RESULTS. Rats were subdivided into groups based upon the incidence of G-induced loss of consciousness (G-LOC).

For multi-exposure rats, the time to G-LOC was substantially increased from 10 seconds on day one to 25 seconds on day 9. No change was noted from day 9 to day 22. Brain pathohistology revealed a trend in severity (neuronal death) with the single exposure with G-LOC > multi-exposure with G-LOC > multi-exposure without G-LOC control. Additionally, kidney, adrenal glands and heart weights were significantly elevated above control rats. CONCLUSION. Increased time to G-LOC suggests early adaptation of rats to frequently repeated G exposure; however, pathohistology suggests that long term exposures present a risk hazard."

Werchan PM, Echon RM, Rogers ME, Sheriff DD, Stavinoha WB. Caffeine enhances 40Hz EEG oscillations during $+G_z$ exposures of rats. (Abstract) Aviat. Space Environ. Med. 1998;69:[In Press]. [15.1]

Abstract: "INTRODUCTION. High $+G_z$ exposure causes a reduction in cerebral blood flow (ischemia), with reductions in brain energy levels and eventual loss of consciousness (G-LOC). The neurochemical mechanism of consciousness and altered states of consciousness (including G-LOC) is very complex and not fully understood, but is believed to be controlled by activation and inhibition of CNS functional circuitries. To investigate the mechanism of G-LOC and the roles of various neurotransmitter systems we have utilized neuropharmacologic compounds and evaluated their effects on cortico-EEG activity during $+G_z$ exposure. To date, agents acting on the adenosine system have shown the most profound effect in altering cortico-EEG activity. While there are limitations to traditional EEG analysis and indexes to define the level of consciousness, we have shown that amplitudes of 40 Hz oscillations (gamma rhythms) are a viable index to evaluate consciousness. To further characterize the mechanism of G-LOC, the effect of caffeine, a potent adenosine receptor agonist, on 40 Hz was investigated. METHODS. Four groups (n=6/group) of rats were given either 0, 15, 30 or 60 mg/Kg caffeine prior to nine 60s centrifuge exposures at $+2.5G_z$ increments beginning at $+0.5G_z$ and ending at $+25G_z$. Intra- and interhemispheric differential EEG signals were collected and power spectral components were analyzed using Fast Fourier Transform. RESULTS. Control (no caffeine) and 15 mg/Kg caffeine exposures to low $+G_z$ levels ($<+10G_z$) resulted in a slight increase in EEG amplitude and continued 40 Hz oscillations during the acceleration period. At medium $+G_z$ levels ($+10$ to $+17.5G_z$) there was a gradual reduction of 40 Hz starting 12-13s after acceleration onset in approximately 65% of the rats. At high $+G_z$ ($+20$ to $+25G_z$) levels there was a cessation of 40Hz oscillations in all rats during the first 12-13s epoch. In caffeine treated rats, low $+G_z$ levels showed no significant changes from control values regardless of dosage. However, 30 mg/Kg and 60mg/Kg caffeine maintained 40 Hz oscillations an additional 21 6s and 45 18s, respectively, with exposure to medium $+G_z$ levels. High $+G_z$ levels following caffeine resulted in depressed 40 HZ oscillations, regardless of dosage, despite a significant extension of EEG activity in the other four frequency bands. CONCLUSION. Caffeine administration of 30 and 60 mg/Kg prior to medium $+G_z$ exposure provides prolonged consciousness in rats as indicated by the maintenance of 40 Hz oscillations."

15.2 Neuropharmacology of Light-Induced Phase Alterations of the Circadian Pacemaker and Gene Expression in the Superchiasmatic Nucleus

The contractor shall provide technical support for an effort involving a detailed investigation of the neurochemical basis of light-induced and optic nerve stimulation-induced gene expression in the SCN of intact hamsters and rat brain hypothalamic slices, respectively. This effort is specifically concerned with the effects of (1) excitatory amino acid receptor agonists and antagonists, (2) gamma-aminobutyric acid receptor agonists and antagonists, (3) neuropeptides, and (4) cyclic nucleotide, phosphoinositide, and arachidonic acid derived second messengers on stimulated expression of the c-fos proto-oncogene, and other c-fos- dependent genes, using both the in vivo and in vitro models. The contractor shall conduct experimentation concerning the biochemical nature of the daytime period of insensitivity of the circadian pacemaker to light stimulation. Under 15.3 The contractor shall provide technical expertise sufficient to conduct the following analytical procedures: a. Isolation and analysis of mRNA by (1) quantitative northern analysis, and (2) quantitative in situ hybridization; b. Preparation of radiolabeled cDNA probes and riboprobes; c. Maintenance of cDNA libraries including subcloning; d. Extra cellular recording of field potential responses to optic nerve stimulation in the hypothalamic slice preparation; e. HPLC analysis of brain slice superfusates and extracts for animo acids and monoamines.

The contractor shall ensure technical personnel involved in this effort will possess expertise in the following technical procedures: a. Basic molecular biological techniques for the study of the regulation of eukaryotic gene expression including, northern, southern and western blotting and hybridization procedures, high resolution electrophoresis of proteins and oligonucleotides, mRNA isolation, autoradiography, preparation and characterization of radiolabeled cDNA probes and riboprobes, and subcloning procedures; b. Extracellular recording of neuronal activity and electrically-evoked field potential responses in hypothalamic slices. Experience must include slice preparation and maintenance, electrical stimulation, superfusion of slices to collect released neurochemicals, and analysis of response data; c. Routine operation of an HPLC. Additionally, PC-computer experience is necessary to support HPLC automation, data collection and data analysis requirements; d. Immunocytochemical and in situ hybridization procedures. Expertise must include skill in histological sectioning and staining techniques using both cryostat/microtome and vibratome; e. Radioimmunoassay of neuropeptides.

Accomplishments

Research reports (DIN A005, DIN A009, DIN A010, and/or DIN A016) from this effort include:

Elliot KJ, Weber ET, Michel AM, Rea MA. Adenosine A1 receptor agonists block light-induced phase shifts of the hamster circadian wheel-running rhythm and c-fos expression. (Abstract) Soc. Neurosci. 1997;23:511(198.5).

Abstract: "Glutamate has been shown to play a role in transmission of photic information to the suprachismatic nuclei via the retinohypothalamic tract. In light of recent demonstrations of

receptor-mediated effects of adenosine on glutamate release in hippocampus and cerebellum, as well as localization of adenosine receptors of retino-recipient collicular neurons, we examined the effects of adenosine receptor agonists (subtype A1=CHA, CCPA: A2=CGS-21680: A3=N6 - benzyl-NECA) and A1 antagonist (DPCPX) on light-induced phase shifts of the hamster circadian wheel-running activity rhythm and light-induced expression of c-fos. Wheel-running activity was monitored in male Syrian hamsters (Mesocricetus auratus) maintained under constant darkness. Animals received i.p. injections of either vehicle or agonist, 30 minutes prior to 10 minutes of 20 lux white light beginning at either CT 14 or CT19 (activity onset = CT 12), then returned to constant darkness. CHA significantly attenuated both phase advances (27 ± 9 mins (mean ± SEM), n=7 vs. controls, 81 ±10, n=8) and phase delays (3 ± 7, n= 6 vs. controls, -51 ±12). Effects of CHA were dose-dependent and clocked by DPCPX (90 ±8, n=8). Phase advances were also blocked by CCPA (45 ± 12, n=8), but not by CGS-21689 (102 ± 7, n=8) or N6 - benzyl-NECA (91 ± 10, n=8). Drugs given without light had no effect on phase. In addition, CHA greatly attenuated c-fos expression in the SCN, and this effect was completely blocked by DPCPX. These data support a role for adenosine A1 receptors in the regulation of retinohypothalamic neurotransmission. This work was supported by the United States Air Force Office of Scientific Research (AFOSR) 2312CA (MAR)."

Erlander MG, Foye PE, Danielson PE, Carson MJ, Cagle M, Gannon RL, Rea MA, Sutcliffe JG. Cloning of differentially expressed genes within hamster suprachiasmatic nucleus (SCN) in response to light entrainment. (Abstract) Soc. Neurosci. 1994;20:162.

Abstract: "The suprachiasmatic nucleus (SCN) is the anatomical seat of the mammalian endogenous biological clock which regulates the temporal expression of strong correlation between the rapid and transient expression of mRNAs encoding immediate early genes (e.g., c-fos) and the time of day in which light is able to reset the endogenous pacemaker. Because most immediate early genes encode transcriptional factors, it is likely that a transcriptional cascade is required for photic entrainment. To test this hypothesis, we have initiated a study to identify/clone differentially expressed mRNAs within the hamster SCN in response to photic entrainment. Hamsters were maintained under LD 14:10 for 14 days and then exposed at ZT19 to light for 15 minutes and then placed back into darkness. Micropunched SCNs of sacrificed hamsters at 30-60 minutes (labeled 30C=30 min control:30S=30 min stimulated) and 180-225 minutes (180C and180S) after light treatment were collected and poly(A) selected RNA extracted. To identify differentially expressed mRNAs a scheme devised for the construction of PCR-based cDNA libraries from small amounts of RNA (30-50ng) was coupled to a newly developed subtractive hybridization procedure. The cDNA libraries appear representative of mRNA populations: concentrations of c-fos and NGFI-A cDNAs are induced >10X in 30S vs. 30C and return to near baseline in180C vs. 180S whereas concentrations of c-jun and cyclophilin cDNA remain unchanged among all four cDNA libraries. 97% of the mRNA mass which was in common between control and light-stimulated libraries was removed by subtractive hybridization. In our initial analysis, several cDNAs unique to 30S and 180S have been obtained and differential expression verified. This molecular approach has the potential of identifying the molecular substrate(s) by which light entrains the pacemaker cells within the SCN."

Gannon RL, Cato MJ, Kelly KH, Armstrong DL, Rea MA. GABAergic modulation of optic nerve-evoked field potentials in the rat suprachiasmatic nucleus. Brain Res. 1995;694:264-70. [see Requirement 26.11]

Rea MA, Cato M, Michel AM, Gannon RL. Lesions of the intergeniculate leaflet block serotonergic potentiation of light-induced phase advances of hamster circadian activity rhythms. (Abstract) Soc. Neurosci. 1995;21:179.

Abstract: "In a previous study (see Gannon & Rea, this volume), we showed that systemic injection of the mixed 5HT1A agonist/antagonist, BMY7378, greatly potentiates light-induced phase shifts, while local injection is without effect. In order to characterize the mechanism of action of BMY7378, we examined the effects of chemical lesions of the 5HT projection to the SCN, as well as bilateral lesions of the intergeniculate leaflet (IGL), on the potentiation of light-induced phase shifts by BMY7378 and similar drugs. Groups of Syrian hamsters received either injections of the serotonergic neurotoxin, 5,7-DHT, or vehicle into the region of the SCN. Groups of other hamsters were subjected either to bilateral lesions of the IGL or to a sham procedure. Activity rhythms were monitored under conditions of constant darkness. Within 2 weeks of treatment, hamsters in all groups received i.p. injections of either vehicle, or 5mg/kg BMY7378, 45 minutes prior to light exposure (20 lux for 10 min) at CT19. Light exposure at CT19 resulted in stable phase advances of the activity rhythm (1.3± 0.2 hr). Systemic injection of BMY7378 resulted in a 233% increase in the photic phase advance (4.3 ±0.4 hr); $p<0.01$). Preliminary results indicate the 5,7-DHT lesions of the 5HT projection to the SCN do not prevent potentiation of photic phase shifts by BMY7378. However, bilateral lesions of the IGL completely block the potentiating effects of the drug (sham+ 0.9 ± 0.1 hr: IGLx = 1.1 ± 0.3 hr). These results indicate that the integrity of the IGL is required for serotonergic potentiation of photic phase shifts."

Rea MA, Cato MJ, Weber ET.. Electrical stimulation of the dorsal raphe nucleus modulates circadian phase in hamsters. (Abstract) Soc. Neurosci. 1997;23:790(309.11).

Abstract: "Systemic administration of serotonin receptor agonists causes phase advances of the circadian activity rhythm when given during the subjective day, and attenuates light-induced phase advances at night. In this study, we investigated the effects of electrical stimulation of the dorsal raphe nucleus at CT8 on circadian phase, and at CT19 on light induced phase advances of the free-running activity rhythm in Syrian hamsters. Animals were implanted with chronic, bipolar, twisted-pair electrodes stereotaxically inserted into the anterior aspect of the dorsal raphe nucleus. After recovery, animals were maintained in constant darkness and wheel-running activity was monitored continuously by computer (Dataquest). Each animal received 30 minutes of electrical stimulation (0.3 mA, 2 msec pulse, 20Hz) beginning either at CT8, or 20 minutes prior to light exposure (10 min @ 20 lux) at CT19. Control animals were attached to the stimulation apparatus without power. Some animals were processed for Fos immunocytochemistry. In a preliminary experiment, 3 of 9 animals that received electrical stimulation at CT8 showed reproducible phase advances (56 ± 12 min). Animals receiving light at CT19 showed phase advances (90 ± 18; n=3) and typical patterns of Fos expression in the SCN. In all animals tested, electrical stimulation during light exposure completely blocked photic phase advances (0 ± 0 min: n=3) and greatly

attenuated Fos expression in the SCN. These results support a role for the dorsal raphe in the regulation of circadian phase. Supported by United States Air Force Office of Scientific Research AFOSR2312CA(MAR)."

Rea MA, Michel AM, Lutton LM. Is fos expression necessary and sufficient to mediate light-induced phase advances of the suprachiasmatic circadian oscillator? J. Biol. Rhythms 1993;8:S59-S64.

Abstract: "Photic stimulation during the subjective night induces the expression of Fos among a discrete population of cells in the suprachiasmatic nuclei (SCN) region of the Syrian hamster. Light appears to stimulate Fos expression only when administered at circadian times (CTs) at which exposure causes a phase shift. Different populations of SCN cells express Fos in response to light pulses that result in phase advances versus phase delays, raising the possibility that different cell populations in the suprachiasmatic hypothalamus participate in light-induced phase advances and delays of the circadian oscillator. Microinjection of excitatory amino acid (EAA) antagonists into the region of the SCN attenuates light-induced phase advances of the free-running activity rhythm and light-induced Fos expression in the hamster SCN. However injection of N-methyl-d-aspartate (NMDA) at CT18, which results in a widespread pattern of Fos expression in the hypothalamus that includes the retino-recipient zone of the SCN, does not produce phase advances of the circadian oscillator. The results demonstrate that both light-induced Fos expression and light-induced phase advances are dependent upon EAA neurotransmission within the SCN region. However, expression of Fos in the SCN induced by the EAA agonist NMDA is not sufficient to cause phase advances of the SCN oscillator."

Weber ET, Cagle M, Rea MA. Local neuropeptide Y blocks light-induced phase advances of the circadian wheel-running activity rhythm in the Syrian hamster. (Abstract) Soc. Neurosci. 1995;21:454.

Abstract: "Neuropeptide Y (NPY)-containing fibers project to the suprachiasmatic nuclei (SCN) from the intergeniculate leaflet of the thalamus. NPY is necessary for non-photic phase shifts (Biello,Janik and Mrosovsky, 1994), and local application during the subjective daytime causes phase advances of the circadian clock, both in vivo (Huhman and Albers, 1994) and in vitro (Medanic and Gillette, 1995). Recent evidence has also implicated NPY in regulation of photic phase-shifting mechanisms (Biello and Mrosovsky, 1995; Biello, 1995). Therefore, we examined the effects of local NPY administration on light-induced phase shifts. Syrian hamsters received 0.3 ul injections into the region of the SCN, of either vehicle (ACSF+1%BSA) or NPY (1.0 or 0.01 mg/ml), 10 minutes prior to light stimulation (10 minutes @ 20 lux) at CT19. Light-induced phase advances (114 ±27 minutes, n=9) were completely blocked by 1.0 mg/ml NPY (-8 ±minutes, n=9), while preliminary results demonstrate attenuation of light-induced shifts by 0.01 mg/ml NPY (47 ±10 minutes, n=5). These results support the hypothesis the NPY regulates the response of the SCN circadian clock to photic stimulation."

Weber ET, Gannon RL, Cagle MA, Rea MA. Pindolol and propanolol attenuate light-induced phase shifts of the circadian activity rhythm in hamster via a putative serotonergic mechanism.. (Abstract) Soc. Neurosci. 1997;23:240(99.5).

Abstract: "In our preliminary studies addressing inhibition of photic phase shifts of hamster circadian rhythms by 5-HT1 agonist, we found that pindolol, a beta-adrenergic antagonist with demonstrated activity at 5-HT1 receptors, inhibits light-induced phase shifts of circadian wheel-running rhythms. To determine whether this effect is a result of action at beta-adrenergic antagonists (pindolol, propranolol, metoprolol, and atenolol, and the experimental compound, ICI-118,551) with varying properties including interactions with 5-HT1 receptors, sympathomimetic activity and beta-1 versus beta-2 specificity, was performed as follows. Wheel-running activity was monitored in male Syrian hamsters (Mesocricetus auratus) maintained under constant darkness. Animals received i.p. injections of either vehicle or drug (5 mg/kg), 60 minutes prior to 10 minutes of 20 lux white light beginning at either CT14 or CT 19 (activity onset = CT 12), then returned to constant darkness. Animals receiving vehicle injection prior to light stimulation at CT 19 demonstrated phase advances of 98 ± 19 mins (mean ± SEM, n= 9). Phase advances were significantly attenuated by pindolol (28 ± 7 mins n = 10) and propranolol (45 ± 11 mins, n =7), but not by metoprolol (111 ± 13 mins, n = 7), atenolol (83 ± 15 mins, n = 5), or ICI 118,551 (74 ± 12 mins, n= 7). Pindolol also inhibited light-induced phase delays at CT 14 (22 ± 9 mins, n=5 vs. controls, 99 ± 12 mins, n= 5). Drugs had no effect when administered without light. From these results, we assert that pindolol and propranolol attenuate photic phase shifts by acting as partial agonists at 5-HT1 receptors. This work was supported by the United States Air Force Office of Scientific Research (AFOSR) 2312CA (MAR)."

Weber ET, Michel AM, Gannon RL, Scott PA, Rea MA. Local 5HT1A/5HT7 agonists dose-dependently attenuate light-induced phase advances of the suprachiasmatic nuclei in vivo. 5th Meeting Soc. Res. Biol. Rhythms. 1996;50:52.

Abstract: "Light-induced phase shifts of the suprachiasmatic nuclei (SCN) are modulated by serotonin (5HT). Pharmacologic evidence suggests that 5HT1A and/or 5HT7 receptors are involved in this modulation, possibly at one or several central sites of action. In order to elucidate the site of action of 5HT agonists on light-induced phase advances and the receptor subtype(s) responsible for serotonergic modulation of phase advances, 8-OH-DPAT and 5-carboxyamidotryptamine (5-CT), compounds with affinities for both 5HT1A and 5HT7 receptors, were administered to hamsters prior to light pulses sufficient to induce phase advances of the circadian clock. Syrian hamsters entrained to a light:dark cycle of 14:10 hours were implanted with cannula guides targeting the SCN. Ten days following release into constant darkness (DD), animals received 0.3 µl of either vehicle, 5-CT or 8-OH-DPAT, 10 minutes prior to 10 minutes of 20 lux white light at circadian time (CT) 19 and returned to DD for 10-14days. Animals receiving vehicle injections prior to light demonstrated advances of 73 ± 8.5 minutes (mean ±SEM). Pretreatment with either 5-CT (1 µM=72.4 ± 15.4, 10 µM=40.0 ±8.4, 100 µM=27.5 ±7.4mins) or 8-OH-DPAT (1 µM=46.6 ±13.8, 10 µM+32.6 ± 5.7, 100 µM=23.2 ± 11.1 mins) dose-dependently attenuated light-induced phase advances, demonstrating that both 5-CT and 8-OH-DPAT act at the level of the SCN. Additionally, systemic 8-OH-DPAT (0.5 mg/kg i.p.) attenuated light-induced phase advances(53.4 ±12.0 mins vs. control 79.2 ± .21 mina). This effect was blocked by pretreatment with (+)WAY100135 (5 mg/kg; 73.2 ±11.4 mins), clozapine (2.5 mg/kg; 75.6 ±9.6 mins) or ritanserin (5 mg/kg; 80.4 ±12.6 mins). Additional experiments using other antagonists (pindolol, MPPF) are underway. In a separate experiment, high affinity

binding of (3H)-8-OH-DPAT in hamster and rat SCN was demonstrated by receptor autoradiography. Preliminary results indicate that in the rat SCN, [3H]-8-OH-DPAT binding was significantly decreased by pindolol (1 μM), a 5HT1A antagonist, and by MPPF (5 μM), a potent 5HT1A antagonist whose activity at 5HT7 has not been described. Ritanserin (0.5 μM), which binds 5HT7, also slightly decreased [3H]-8-OH-DPAT binding. These results suggest that both 5HT1A and 5HT7 are present in the rat SCN. A similar study of binding in the hamster SCN is underway. Together, these results demonstrate that serotonin acts directly at the level of the SCN to modulate photic input. Due to the pharmacological similarities of 5HT1A and 5HT7, it remains unclear which of the receptor subtypes is responsible for that modulation."

Weber ET, Gannon RL, Michel AM, Gillette MU, Rea MA. Nitric oxide synthase inhibitor blocks light-induced phase shifts of the circadian activity rhythm, but not c-fos expression in the suprachiasmatic nucleus of the Syrian hamster. Brain Res. 1995;692:137-42. [see Requirement 26.11]

26. TASK ORDER REQUIREMENTS

26.1 Fabrication and Modification of Acceleration Protective Systems

The contractor shall provide a Fabrication Specialist, equipment and materials needed to support the scope of this task. At the conclusion of the task, the contractor shall deliver any acceleration protection garments developed and equipment purchased.

Accomplishments

KLSI assigned a Soft-Goods Fabrication Technician to the effort and purchased an ultrasonic sealer to improve pressure bladder fabrication capability to provide soft-goods fabrication support to researchers involved in test and an evaluation of acceleration protection garments. A Fabric Sealing System was purchased from Branson Ultrasonics Corp., Danbury, CT. The device was employed in the fabrication of 25 pair of ATAGS pressure socks and was used to support the fabrication of other life support equipment. Fabrication projects included the development of two ReEntry Advanced G-Suits (REAGS), a vacuum device for animal (swine) retention used during centrifuge studies, modified pressure vests for a thermal study and modifications to flight suits. Support was also provided for the fabrication of Advanced Technology Anti-G Suits.

26.2 Breathing Systems Research

The contractor shall upgrade the capabilities of three Government furnished breathing simulators using commercially available components. The contractor shall be responsible for all software development and testing as well as for the delivery of all software developmental, test and source code documentation for this upgrade. These three units have been divided into three systems. (A016, A017, A018)

(a) Two of these simulators (Systems #2 and #3) must replicate actual individual breathing patterns. Each of these simulators must:

(1) provide a system capable of duplicating or copying frrom stored electronic or magnetic media, breathing patterns taken during various activities such as rest, exercise, speech, and anti-G straining maneuvers. (A018, ref: para 5.a. below) Each will include an electronic controller amplifier, appropriate interface(s), and a new servo motor.

(2) have variable flow rate capability of a maximum of 450 liters per minute, a six liter stroke volume and a variable number of breaths per minute. These simulators must have precise repeatability of breathing profiles. System accuracy shall be measured by inputting a flow profile into the servo controller and measuring the output at the mask or flow measuring device. Output shall not deviate from the input in terms of slopes, rise times and amplitudes by more than ± 3%.

(b) Two of these simulators (Systems #1 and #2) shall be upgraded with water-cooled heat sinks enabling the simulators to operate to 70,000 ft pressure altitude.

(c) All work pertaining to the 70,000 ft pressure upgrade shall be accomplished at the contractor's facility. All work pertaining to the upgrade associated with replicating actual breathing patterns (Systems #2 and #3) will be accomplished and tested at Brooks AFB, Texas.

The contractor shall establish procedures and policies for chamber (10 research chambers in Bldg 160) configuration and maintenance operations as well as develop a long range plan for chamber capabilities and upgrade/repaid. End product is a technical report. (A016)

The contractor shall develop methods for conducting safety inspections and evaluation of pressure vehicles, to include, wiring, control systems, and plumbing so as to determine if any unacceptable hazards exist. End product is a technical report. (A016)

The contractor shall analyze data collected from field tests of B-1 OBOGS and provide a report documenting performance. (A016)

The contractor shall assemble in Government facility and evaluate performance of hybrid oxygen system using Government furnished equipment, (GFE) to demonstrate the technical feasibility of generating and liquefying oxygen from a molecular sieve oxygen generating system (MSOGS), and provide a report on its performance. (A016)

During the course of above R&D activities, the contractor shall provide general technical advice and consultative support to R&D efforts. (Such efforts shall include but not be limited to technical transfer of Molecular Sieve Oxygen Concentrator (MSOC) and USAF and tri-service/joint research and development programs involving OBOGS.)

Accomplishments

Work accomplished under the Oxygen Breathing Systems and Research Chamber portion of this task was divided into three general areas: 1) Variable Profile Breathing Simulator; 2) Research Chambers - Configuration and Maintenance; and 3) Research Chambers - Safety. The last two efforts required specialized documentation in the form of guidelines/procedures/methods and recommendations in place of a formal Technical Report. CFT management decided that outlining current chamber capabilities required a more detailed document than originally requested and because of the late notice, KLSI would be given additional time to accomplish this portion of the task. The plan was to revise each Research Chamber Technical Manual so as to describe current capabilities, maintenance and inspection procedures. The manuals were completed under a follow-on task.

There were two goals identified for the task of configuration and maintenance of the Research Chambers. First, and probably the most important, was to assist in establishing procedures and policies for chamber configuration and maintenance. Prior to this tasking, efforts were made to safely accommodate the installation of research equipment and modifications to the chambers. However, no central review process took place as new protocols called for changes to chamber configuration. The second goal was to perform a configuration baseline for each of the ten research chambers. Each of the chambers had an operational limit established when it was manufactured/installed. Years of "adequate" maintenance combined with repeated modifications had undoubtedly affected their capabilities.

Assistance was provided in the development of a configuration control program for the research chambers. Actual deliverables included the developing of two Operational Instructions. These were OI 127-2 entitled "Chamber Configuration Control Program" and OI 127-8, "System Risk Assessment and Control Program". These OI's assign responsibilities for the Configuration Management Program and Risk Committee as well as creating the position of Lead Engineer for Chamber Operations. Data base information was completed which describes some current capabilities for each research chamber. This information was sent to NASA for their records and will also be used in conjunction with researched chamber data to produce the deliverable.

Technical assistance was provided to CFTS Chamber Maintenance Staff concerning the removal and installation of the new brine tank (chamber cooling system) used in chamber A7.

Technical assistance was provided to CFT Management, CFTS Management, Chamber Operations Management Staff, and Base Bio-environmental Health Office concerning the removal and disposition of Methylene Chloride used as a source of coolant in the environmental system for "E" chamber. This issue is not completely closed. A study was funded to locate a suitable replacement coolant source.

A document entitled "Chamber Safety Inspections" was written for CFTS management which outlined specific chamber safety and maintenance concerns.

Technical assistance and input was provided to: a) CFTS Chamber Staff concerning Ozone Depleting Compounds found in the chamber area, b) CFTS Chamber Staff, Base Civil Engineering, and Subcontractors/Vendor concerning the Asbestos Abatement Program for building 160, c) CFT Management concerning several "incidents" occurring in these research chambers during the task period and d) CFTS Chamber Management Staff concerning the writing of CFTS Operating Instruction (OI) 127-3, establishing guidelines for conducting a viable safety program, entitled "Safety Program" dated 2 December 1993.

The Lead Engineer for Chamber Operations (LECO) provided technical and safety input to the chamber staff concerning various experiments. Examples of the types of activities performed follows:

1. Fire Fighters Chemical Protective Ensemble Thermal Stress Test

Technical guidance was provided to the Air Force (Capt O'Connor, AL/CFTS) on test requirements/test procedures for the Fire Fighters Chemical Protective Ensemble Thermal Stress Test study. Testing started August 93. Several technical interchange meetings were attended with Capt O'Connor (PI), CFTS Chamber Management Staff, Division Safety Officer, and the testing/maintenance function to discuss safety, test requirements, setup, and instrumentation needed for this study. The LabView data acquisition program and test hardware was modified to meet users needs.

2. NASA Regulator Evaluation and Study.

3. The Effect of Supplementary Oxygen Use On Night Vision Goggles.

4. B1-B Molecular Sieve Oxygen Generating System.

5. Evaluation of High Altitude Parachutist Oxygen Equipment for Medical Use.

6. Smoke and Fume Protection.

7. The Effect of Exercise on Altitude Decompression Sickness.

Technical assistance was provided on all research chamber equipment installations:

1. Vibration Table to be installed in research chamber A2.

2. Nash Pump installation on C pad.

3. Intercom System - Acquisition and Installation in "C" chamber.

4. Kinney Pumps - Acquisition and installation.

5. RD Valve for B Chamber.

6. Interfaced with Civil Engineering, Vendor and Procurement concerning installation of the new brine tank for chamber A7.

7. Provided technical and planning assistance to chamber maintenance staff concerning the installation of the OBOGS/ LOX testing setup. Originally the plan was to have this unit plumbed into research chamber A1; however, it will now be going into building 161.

8. Provided technical assistance to CFTS Chamber Maintenance Section and Vendor concerning the condenser water bypass control system installed on "York" pad.

9. Provided technical assistance to CFTS Management concerning the upgrading of the altitude chamber facility. Formulated a list of needed equipment, background to justify, impact of not funding this facility upgrade, and a list of customers supported.

Technical assistance was provided in the area of equipment repair. Examples include:

1. Interfaced with Parker Kinetics Design (PKD) to ensure altitude control loop ("E" chamber, MicroMax) was properly tuned.

2. Provided technical assistance to CFTS staff on the refurbishment of several MGA 1100 gas analyzers.

3. Provided technical assistance to chamber staff (test and evaluation section) on the repair of several breathing simulators.

In the area of maintenance, technical and management guidance was provided by recognizing and documenting the need for an electronics technician in Bldg. 160 (CFTS Research Chamber Facility). This documentation also outlined specific duties and responsibilities for this technician.

Input to chamber management concerning the necessity for refurbishment of electrical wiring, window seals and various other systems for each of the chambers was provided. Assistance was provided in the coordination with Depot (Hill AFB, POC Mr. Don Westenskow) and AL/CFTS Chamber Staff concerning these issues and how they can best be resolved.

Consultation/technical assistance was provided to the Air Force and NASA on test requirements/ test procedures for ASFSI's Model ABR 250-G6 Oxygen Regulator. Several technical interchange meetings were attended with NASA and American Safety of Flight to discuss test setup, requirements, and preliminary results.

Training to chamber staff was provided on various aspects of oxygen regulator test setup and data acquisition. The Armstrong Laboratory Engineering Support Personnel was provided training on various aspects of oxygen regulator design principles and altitude chamber /test setup fundamentals. Also, guidance was provided in calibrating strip chart recorders and carrier demodulators used in chambers B-3 and A-5/6 on the NASA regulator test.

LabView Data Acquisition software was designed and programmed for the NASA/ASFSI regulator testing. This initial program was used for steady state testing and later modified to collect and analyze dynamic profile data.

Consultation/technical assistance was provided to the Air Force (AL/CFTS) in the testing of various Air Force oxygen regulators. Training was also provided to three chamber technicians in the area of test and measurements.

Technical and planning assistance was provided to the chamber maintenance staff concerning the control system of "E" chamber and to CFT and chamber management concerning the research chamber operation maintenance program.

The research chambers were inspected for possible safety hazards. Assistance/input was provided to the chamber management concerning the necessity for refurbishment of electrical wiring and window seals for each of the chambers.

Technical and planning assistance was provided to CFTS/chamber management concerning the removal of asbestos in the research chamber area.

The documentation of current chamber capabilities is complete. These findings were integrated into Technical Manuals created some time ago by CFTS chamber technicians. These technical manuals are maintained in the chamber operations area of Bldg. 160.

The operational and safety features of the Hybrid Oxygen System (HOS) was discussed with the HSC safety office. The safety office stated that construction of the HOS in either Building 160 or Building 161 was acceptable. The Air Force selected Building 161 because of the greater space available.

The helium refrigeration system was operationally tested. In one leg of the refrigeration circuit a small leak was detected. Upon repair, the system maintained its charge pressure.

Verification of equipment operating within its specified parameters is and was conducted prior to system installation. In following this practice it was found that the HOS OBOGS system, an Essex oxygen concentrator, was not operating properly. It was shipped back to Essex for refurbishment. On receipt of the refurbished unit, the performance was checked and found to be acceptable with concentration readings of 92% at an inlet pressure of 60 psig and product flow of 40 NLPM.

A detailed process flow and electrical schematic for the system was produced. Concurrently, the data acquisition and control software was developed with fail safe features that considered different modes by which the system should be shut down. These features minimized the likelihood of operator error.

Delays were encountered with the Hybrid Oxygen System (HOS) project due to slow reception of GFE parts for the system, a change in the site for the system set up, refurbishment of the new site to house the system, vacuum leaks, a malfunction of the air directional valve within the vacuum vessel and problems with the roughing and high vacuum, turbo-molecular pump.

The goal of the B-1B OBOGS Flight Evaluation was to determine the effects of temperature and humidity on the B-1B OBOGS. Over the period of the task several technical documents related to the development of the instrumentation package were reviewed. The test plan for the effort was reviewed and comments were submitted to ASC/ENSC. Also, the data transmission procedures between Dyess AFB and Brooks AFB were coordinated.

Technical and consultative support was provided over a wide range topics concerning OBOGS research, development, design, flight qualification, man-rating, performance, maintenance, and physiology and chemical contamination issues. Several of the programs supported were: High Performance OBOGS, tri-service OBOGS programs, and existing and future aircraft OBOGS systems.

The High Performance OBOGS (HP-OBOGS) technology transfer efforts made significant progress. The Government issued Arbor Research Corporation, Ann Arbor, Michigan an exclusive license for this technology. A Cooperative R&D Agreement (CRDA) between Armstrong Laboratory and Arbor Research Corporation was initiated on 23 September 1993 for a period of one year.

26.3 Sustained High Acceleration RDT&E

The contractor shall conduct a research and development effort for the ATAGS program. Specifically, the effort will address improved fit and function, increased performance, and enhanced operational suitability. The program will be associated with the ongoing Armstrong Laboratory advanced development (6.3) program will be associated with the Armstrong Laboratory's support of the Human Systems Program Office's engineering and manufacturing development effort (6.4) for ATAGS. Provide engineering drawings of ATAGS systems. (DIN: A004, A005, A010, A011, A013, A016, A018)

The contractor shall conduct an exploratory and advanced development effort for the Acceleration Protective System Optimization (APSO) program, within the Armstrong Laboratory. The APSO program is aimed at improving upon established technologies form the ATAGS and COMBAT EDGE programs. The effort shall address optimized G-suit pressure schedules, improved integration, thermal load reduction, ensemble fit on female crew members, and extended coverage. (DIN: A004, A005, A010, A011, A018, A019, A020, A021)

The contractor shall conduct an exploratory and advanced development effort to determine the physiologic effects of high sustained acceleration and to develop new systems, procedures and training to counteract these effects. Specifically, this effort will address innovative technologies and conditions to include but is not limited to reclined seats and very high accelerative loads (> 9 $+G_z$). (DIN: A004, A005, A010, A011, A016, A019, A020, A021)

The contractor shall configure and maintain computer data acquisition systems and provide presentation and publication support for this effort. (DIN: A017)

The contractor shall assign a senior research scientist with primary responsibility of leading the contractor research and development effort on anti-G suits. This investigator shall consult with personnel from the Crew Technology Division, the APSO program, the advanced development program and the Human Systems Program Office to establish priorities and determine research direction. (DIN: A004, A005, A010, A011, A016, A018, A019, A020, A021)

Accomplishments

To conduct research and provide support for the advanced development and the manufacturing development of the Advanced Technology Anti-G Suit (ATAGS) KLSI assigned a senior acceleration scientist, an engineer with computer aided design expertise, and a computer applications specialist. KLSI conducted a series of in-house research and development efforts to improve the fit, function and performance of the ATAGS. This in-house effort was conducted in conjunction with an advanced development effort that was accomplished via a KLSI subcontract with the David Clark Co. Inc. The combined in-house effort and David Clark Co. subcontract provided a synergy that led to significant improvements in the ATAGS fit, function and operational suitability.

a. ATAGS Inflation Times. The in-house evaluation of the ATAGS showed that the integrated inflation hose of the ATAGS generated excessive resistance to air flow and was a major factor in increasing the ATAGS inflation time. The ATAGS inflation hose evaluation and flow rate improvement effort focused on three areas: the suit-to-aircraft connector, the inflation hose design, and the hose-to-suit connection. If was found that the suit-to-aircraft connector and the inflation hose did not contribute greatly to air flow resistance. The greatest single contributor to increased flow resistance was found to be the inflation hose-to-suit connection point. Working under the KLSI subcontract, the David Clark Co. redesigned the inflation hose and improved the integration of the hose-to-suit connection to reduce flow resistance. These improvements were designed into the David Clark fabricated suits. The design of the ATAGS fabricated in the Armstrong Laboratory, Life Support Equipment Development Laboratory (LSEDL) was also changed to incorporate the improved inflation hose design.

b. ATAGS Donning/Safety Buckles. KLSI conducted an evaluation to determine the number and location of the buckles required to adequately restrain the suit in the event of a zipper failure. An ATAGS was modified in the LSEDL with two buckles on each leg. One buckle was located at the top of the thigh and the second buckle was located at the knee. An evaluation of this design in the Life Support Equipment Integration Laboratory determined that the two buckle configuration did not adequately restrain the suit and created a pressure point at the knee. The design was modified by adding a third buckle on each leg and the knee buckle was moved to above the knee. Integration testing was repeated and the three buckle design was found to be satisfactory. The method of buckle integration was evaluated by conducting pressure tests and zipper failure tests on the suit. When the suit was pressurized with the buckles connected and the

legs unzipped, the buckles were found to stay secured at a suit pressure of 5 psi. A number of tests were conducted in which the ATAGS leg zippers were intentionally failed at maximum suit pressure (10.5 psi.). When the zipper failed, the volume of the partially restrained suit rapidly increased and the suit pressure dropped to less than 1 psi. The buckles remained secure during the zipper failure part of the test; however, when the suit was allowed to reinflate, the buckles failed at pressures of 5.0 - 7.0 psi. Suit reinflation to the point of buckle failure required 2-3 seconds. This time was viewed to be adequate for the pilot to decrease the G-load on the aircraft. In view of both the time allowed and the suit pressure that the buckles contained, the buckle type and the method of attachment was determined to be satisfactory. This finding was supported by the fact that the buckles held in place during the in-flight inadvertent zipper opening that occurred on during a Navy flight test.

c. ATAGS Design Improvements. As a part of the KLSI subcontract with the David Clark Co., an evaluation of the ATAGS design was conducted to identify and eliminate design issues. The ATAGS fabricated in the LSEDL were experiencing seam failures in the abdominal bladder when the suit was inflated at high pressures. The failures were most pronounced in the larger sized suits. An analysis of the ATAGS design determined that the abdominal bladder was not adequately contained by the internal restraint layer of the suit. To remedy this problem the internal restraint material in the abdominal bladder area was changed from a light weight Nomex to the heavier grade Nomex used for the external restraint layer. In addition, it was found that the sewing patterns around the lower portion of the abdominal bladder did not adequately enclose the abdominal bladder and created stress points. The sewing pattern was modified to ensure proper enclosure of the bladder. These changes remedied the design problem and allowed the suits to pass pressure tests at 5 psi. with the suit not mounted on a mannequin. When the suit was mounted on a mannequin, the improved abdominal restraint allowed the David Clark fabricated ATAGS to pass proof testing at 150% of the operational suit pressure. During their evaluation of the ATAGS design, the David Clark Co. discovered that the direction of material as specified in the LSEDL's ATAGS patterns was incorrect. Fabrics have less stretch across the width of the material. The ATAGS patterns must be aligned so that the least stretchable direction of the fabric is around the circumference of the suit. Correcting the ATAGS patterns for the material direction helped decrease the inflated volume of the suit by decreasing the stretch.

d. ATAGS Drawings and Patterns. The LSEDL patterns for all 180 patterns for the 9 sizes of the ATAGS (20 patterns per suit size) were digitized and placed in an AutoCAD data base. The David Clark drawings were reviewed and converted to meet USAF specifications for level 2 drawings. The changes included adding a USAF standard format materials list, providing more drawing detail and changing the drawing title block.

e. ATAGS Inflation Time Evaluations. A centrifuge evaluation of the ATAGS inflation time and G-protection during high-G onset acceleration was completed. The purpose of this study was to compare the inflation time of the standard CSU-13B/P with a slow, standard and fast inflating ATAGS. The study involved both manned and unmanned evaluations. The unmanned evaluations showed that the ATAGS, including the fast inflating ATAGS, does inflate slower than the standard CSU-13B/P; however, the manned evaluations demonstrated that the G-protection provided by the ATAGS equal to or better than the CSU-13B/P. The centrifuge subjects used in

this study all wore small or medium sized suits. Manned and unmanned evaluations have shown that the larger ATAGS inflates even slower than the suits worn by these subjects. The David Clark Co. developed a modified inflation hose that improved the flow rate of the suit and a large size ATAGS (Size 8) with the inflation hose modification was evaluated on the centrifuge during high-G onset accelerations. The centrifuge evaluation did identify that the ATAGS was still slower inflating than the CSU-13B/P; however, the subject observed that the G-protection provided by the suit was very good. Further evaluation and modification of the large size ATAGS to reduce the suit volume and improve the inflation times are needed to optimize the ATAGS's performance.

f. ATAGS Integration, Kneeless ATAGS Fabrication and Evaluation. In an effort to improve the integration of the ATAGS with USAF anti-exposure garments, the LSEDL fabricated four ATAGS with the knees open in the patellar and popliteal areas. The objective of this modification was to improve pilot mobility and comfort when the ATAGS was worn over bulky anti-exposure garments. Both centrifuge and cockpit integration evaluations were conducted with the kneeless suit. The cockpit integration study included F-15 and F-16 cockpit entry and egress evaluations. A subjective assessment showed that the knee mobility of the subject was marginally improved by using the kneeless ATAGS. The centrifuge evaluations were conducted with three subjects being exposed to various acceleration profiles. One of the subjects experienced severe knee pain and petechial hemorrhage in the patellar area while wearing the kneeless suit. Another subject experienced petechial hemorrhage without noticing pain and the third subject experienced no pain or petechial hemorrhage. Based on the marginal improvement in mobility and the occurrence of knee pain and petechial hemorrhage, the kneeless ATAGS concept was discontinued.

g. ATAGS and COMBAT EDGE Thermal Load Reduction. In an effort to improve aircrew comfort and reduce the thermal load imposed by the ATAGS and the COMBAT EDGE pressure garment, KLSI negotiated an extension of the David Clark Co. subcontract to develop and fabricate this equipment from advanced materials. This effort includes an evaluation of pressure bladder materials that are fabricated from light-weight water vapor permeable materials (Gortex) that are designed to allow better evaporation of perspiration. The ATAGS and COMBAT EDGE garment are multi-layered with an inner liner, two layers of bladder material and an external restraint layer. In some applications, breathable materials have been used successfully; however, the multi-layered garment may defeat the "breathable" properties of the material. On the other hand, the breathable materials are very light weight and can bonded to a high strength nylon base fabric to form an extremely flexible, strong and light weight bladder. Current evaluations indicate that a very comfortable light weight garment can be successfully fabricated.

h. Female G-Suit Fit. As a part of an in-house effort to improve the fit of the CSU-13B/P anti-G suit for female aircrew, KLSI modified the suits and conducted laboratory and centrifuge evaluations to determine the effectiveness of the modifications. An evaluation of the G-suit fit on females indicated that the abdominal bladder of the suit will often ride up over the rib cage and interfere with the performance of the anti-G straining maneuver. The evaluation also found that the suit did not fit well in the hip, calf and abdominal areas. Lowering the abdominal bladder and appropriate tailoring of the suit eliminated these problems. Modified suits were evaluated on the centrifuge and were found to be effective. Two female F-16 pilots were referred by their flight

surgeons to the Armstrong Laboratory for G-suit fit evaluations. In both of these cases, the modification improved the fit and performance of the pilot's anti-G suit. The Human Systems Program office certified the modified suits to be "safe to fly" and the suits were issued for operational use. The development of a USAF Technical Order change to implement the suit modification will be conducted under the Armstrong Laboratory's Female Acceleration Tolerance Enhancement project.

i. Anti-G Suit Testing Laboratory. This tasking supported in-house programs. Included in this support was the continued development of a state of the art laboratory for the unmanned testing of anti-G suits. The automated testing system included Apple Macintosh II microprocessor with an onboard National Instruments NB-MIO-16 multipurpose data acquisition board driven by LabView 2 software. The computer operated a suit pressurization system that included a pressure source, G-valve, tubing and connections. Data was collected from an inline flow meter and pressure transducers to determine suit inflation times, pressures, air flows, leak rates and suit volumes. Suit testing protocols were developed to evaluate new and modified anti-G suits prior to their use in centrifuge testing. This system was used extensively to determine ATAGS volumes and inflation times. The system was also used for ATAGS pressure and leak testing. Data from the anti-G suit testing laboratory was used to establish the suit performance specifications for the engineering and manufacturing development phase (6.4) of the ATAGS program.

j. G-Tolerance/Training. A centrifuge study was conducted to evaluate relaxed Gradual Onset Relaxed (GOR) G-tolerance immediately following exposure to High Sustained $+G_z$ (HSG). This study indicated that a subjects GOR tolerance is generally lower immediately following exposure to high sustained G. This reduction in post-HSG acceleration tolerance may place a greater demand on the aircrew's G-protective equipment or force the aircrew to perform a more vigorous anti-G straining maneuver to maintain vision and consciousness. Recognition of this possibility is relevant to aircrew G training.

Research reports (DIN A005, DIN A009, DIN A010, and/or DIN A016) from this effort include:

Self DA, White CD, Shaffstall RM, Mtinangi BL, Croft JS, Hainsworth R. Differences between syncope resulting from rapid onset acceleration and orthostatic stress. Aviat. Space Environ. Med. 1996;67:547-54.

Abstract: "BACKGROUND AND HYPOTHESIS: Orthostatically-induced syncope is accompanied by venous pooling and vasodilatation. Loss of consciousness during head-to-foot acceleration (G-LOC) in aviators may be caused by a different mechanism, as venous pooling should be prevented through the use of an anti-G suit. This research was conducted to test the hypothesis that in individuals wearing a well-fitted anti-G garment, no important changes occur in the volume of dependent regions during loss of consciousness resulting from rapid onset acceleration stress. Further, this work compares venous pooling patterns in G-LOC subjects to patterns seen during syncope in volunteers and patients subjected to orthostatic stress. We conducted the tilt/LBNP tests to establish what level of venous pooling was required to induce syncope in the absence of a hydrostatic component (other than 1 G) and to confirm that our equipment was sensitive enough to detect volume changes large enough to cause syncope.

METHODS: Shifts in blood volume to the calf, thigh, and abdominal segments were compared in subjects with G-LOC to those in subjects taken to presyncope with orthostatic stress created by upright tile and lower body negative pressure (LBNP). Centrifuge subjects were exposed to a 15 s rapid onset (6G/s) $+5G_z$ exposure on the centrifuge while remaining relaxed and wearing a well-fitting anti-G suit, but with the anti-G suit pressure inactivated. Results: Blood volume decreased an average of 14.9 + or - 22.1 ml in the calf segment; increased an average of 64.1 + or - 7.9 ml in the thigh segment, and decreased an average of 80.0 + or- 29.7 ml in the abdominal segment. The mean net change in volume of the three combined regions was not significantly different form zero. Presyncope was induced in subjects by a progressive exposure to upright tile, and then addition of LBNP at -20 mmHg and -40 mmHg. In the tilt/LBNP group, there was a net increase of 1022 + or - 269.8 ml for the combined segments. Changes in all three segments were significantly different than the mean segmental volume changes seen in centrifuge subjects at G-LOC endpoints. Significant changes from baseline mean arterial pressure, but not heart rate were also seen within but not between the 2 groups, with mean eye level blood pressure (ELBP) falling an average of 45.6 + or - 7.7 mmHg in the tilt/LBNP group at syncope and 105.1 + or - 15.5 mm Hg in the centrifuge subjects at G-LOC. CONCLUSIONS: These differences suggest that G-LOC may be due entirely to hydrostatic effects, with venouspooling being prevented by the wearing of an anti-G garment, even when it remains uninflated."

26.4 ATAGS and COMBAT EDGE Development

The contractor shall develop a plan detailing how this task will be managed. The plan shall include milestones and reviews required to insure that task requirements are met and shall include details on how subcontract performance shall be monitored. (DIN A013)

The contractor shall analyze the ATAGS design for reliability and maintainability (R&M) and for durability. The analysis shall identify design changes that will increase the reliability of ATAGS and enhance the maintainability and durability of ATAGS in the field. Design changes shall eliminate or reduce high stress point loading of the bladder layer. Wearer comfort and mobility shall be optimized in any design changes. (DIN A016)

The contractor shall conduct an engineering and materials study to optimized the ATAGS design selected for fabrication. The materials selection process shall address strength of materials required for ATAGS to function, as well as comfort and mobility of the wearer in relation to the materials selected. (DIN A016)

The contractor shall analyze the ATAGS design for producability and make recommendations which will reduce the production costs of ATAGS. The analysis shall include bladder fabrication methods and restraint garment sewing methods. (DIN A)16)

The contractor shall fabricate five prototype ATAGS incorporating any approved changes from the engineering and materials studies. Document all changes. (DIN A018)

The contractor shall develop a fabrication specification following the format and contents of MIL-STD-490A, Appendix 90. (DIN A012)

The contractor shall develop and fabricate five additional ATAGS using the technology developed in the materials study. The goal of this development effort is to incorporate materials study. The goal of this development effort is t incorporate materials that improve comfort and mobility while decreasing thermal strain. The configuration and reliability of these suits will be suitable for centrifuge and flight testing (DIN A018)

The contractor shall develop and fabricate one prototype COMBAT EDGE counterpressure garment (jerkin) using the technology developed in the materials study. The goal of this development is to incorporate materials that improve comfort and mobility while decreasing thermal strain. This prototype garment will be suitable for centrifuge testing. (DIN A018)

The contractor shall install design data for the new five ATAGS and COMBAT EDGE garment (incorporating materials technology) onto the autoCAD system provided by the Air Force for use at the Armstrong Laboratory and demonstrate manipulation and production of engineering drawings for each ATAGS size. These drawings shall meet the CALS specification as stated in MIL-HDBK-59A. (DIN A018)

The contractor shall provide support for a test and evaluation program of the COMBAT EDGE and ATAGS systems at high altitude. (DIN A016)

The contractor shall provide drawings, patterns and any fabrication technique changes for the modified, faster inflating ATAGS.

The contractor shall provide the engineering prototype ATAGS used to develop and test reduced inflation time modifications.

Accomplishments

KLSI provided 11 ATAGS in 5 sizes, 1 COMBAT EDGE counter-pressure garment, drawings and patterns for the basic ATAGS for the 5 sizes, changes to the drawings and patterns for the Advanced Materials ATAGS and the Improved Inflation Time ATAGS, patterns for the Advanced Materials COMBAT EDGE counter-pressure garment, the basic ATAGS production performance specification, altitude test documentation and support, ATAGS test reports, monthly reports, trip reports and a task order final report. This task order completed the primary efforts needed to complete ATAGS development and transition the project to Engineering and Manufacturing Development.

KLSI established a subcontract with the David Clark Co. Under this subcontract, the David Clark Co. conducted engineering evaluations of the ATAGS design to provide input for required technical improvements, provided five flight-ready ATAGS, and provided all required documentation.

KRUG Life Sciences Inc.:

a. Conducted a design analysis that included a review of potential failure modes, an inlet hose evaluation and an analysis of the ATAG's internal restraint (side release buckles).

b. Conducted an engineering and materials study that included the following areas: Velcro selection, urethane coated nylon pull testing, Velcro/flap patterning for take-up panel covers, improved buttocks seam construction, improved zipper integration at waist zipper, improved knee restraint fabrication and loop tape selection

c. Conducted a production analysis focused on the potential use of Radio-Frequency (RF) heat seaming techniques for the suit bladders. The RF technique was evaluated with several different types of materials. Thigh section suit bladders were used to evaluate the strength and durability characteristics of the seams.

d. Fabricated five prototype ATAGS, sizes 2, 4, 5, 6, and 8. The size 8 suit was delivered in December 1993 and in-house testing was conducted in Jan 1994. Following the in-house testing, the size 8 suit was returned to the David Clark Co. to retrofit the restraint buckles. The size 2 and size 5 suits were delivered in Feb 1994 and the size 4 and size 6 suits were delivered in April 1994. After the size 2, 5 and 8 suits were fabricated, the David Clark Co. determined that the patterns for the outer restraint layer should be reoriented. The Air Force patterns that were provided to the David Clark Co. showed the fabric (direction of goods) oriented with the warp running the length of the patterns. Pressure and cycle testing of the first three suits showed seam stretches and excessive material elongation. The material was reoriented for the size 4 and 6 suits.

e. Developed a product performance specification that provided detailed instructions for each step of the ATAGS production process. This specification was validated by using the specification to produce three ATAGS in the LSEDL. All discrepancies or questions were presented to the David Clark Co. and a final, corrected specification was provided.

f. A Task Order management plan was developed and included with the KLSI proposal. The management plan included all features identified in the first phase of the task. Work under this phase of the task was conducted concurrently with Phase 1.

g. The KLSI contract with the David Clark Co. Inc. was modified to include the development and fabrication of five (5) Advanced Materials ATAGS. The David Clark Co. researched and evaluated a number of different fabrics for potential use as the ATAGS outer restraint layer and the ATAGS bladder.

h. The Advanced Materials ATAGS was fabricated with a staple fiber Nomex outer restraint layer, a Goretex bladder and a light weight Nomex inner lining. The patterns and fabrication procedures developed in the first phase of the David Clark Co. contract were used to produce the advanced materials suit. Five Advanced Materials ATAGS, sizes 2, 4, 5, 6, and 8. were

fabricated. Prior to their delivery to KLSI, the David Clark Co. leak tested the suits at 10.5 psi. and pressure tested the suits at 13.5 psi.

i. Developed and delivered an Advanced Materials COMBAT EDGE vest. The David Clark Co. conducted an analysis of external restraint layer and bladder materials to determine a suitable material for the COMBAT EDGE pressure garment (vest). The research effort conducted for the ATAGS bladder materials applied to the COMBAT EDGE vest and the Goretex trilaminate was selected at the COMBAT EDGE bladder material. Due to the lower operating pressures in the vest, a lighter weight restraint layer was thought possible for the COMBAT EDGE vest. The standard Nomex (4.3 oz./sq. yd.) and a light weight Nomex (3.45 oz./sq. yd.) was evaluated for seam strength and overall effectiveness. Based on the David Clark Co. analysis, use of the light weight Nomex would require an extensive redesign of the COMBAT EDGE vest to adequately strengthen the seams of the vest. Based on this analysis and the minimal savings gained in the weight of the garment that would be gained by using the lighter material, the standard Nomex material was used for the vest restraint layer. In the final configuration, the Advanced Materials COMBAT EDGE vest was approximately 8 oz. lighter than the standard CSU-17/P COMBAT EDGE vest.

j. Incorporation of Design Changes. The fabrication Advanced Materials ATAGS did not require changes to the basic ATAGS patterns and engineering drawings developed under Phase 1 of this Task Order. Government furnished patterns and engineering drawings were used to fabricate the Advanced Materials COMBAT EDGE vest. Other ATAGS document modifications, not related to the changes in materials, were incorporated into the patterns and drawings. These modifications included the change from a donning hook at the waist of the suit to a donning snap The addition of overruns at the top and bottom of the leg zippers and the addition of a zipper slide retention strap at the bottom of the leg zippers. During the course of the Task Order, the ATAGS transition process to the Human Systems Program Office, Life Support Systems Division was completed. All patterns and engineering drawings were upgraded to meet DT&E requirements.

k. ATAGS and COMBAT EDGE Acceleration and Altitude Testing. During the period of September 1993 to October 1994, KLSI provided a highly experienced Lead Engineer (Electrical Engineering) and a similarly experienced oxygen systems technician to support the high altitude test and evaluation of COMBAT EDGE, ATAGS and other related systems. This effort tasked KLSI to develop Standard Operating Procedures (SOP) for high altitude test equipment, provide training for Government personnel in the testing of high altitude equipment and support the testing of high altitude equipment. Standard Operating Procedures were developed for the following equipment: Validyne Model CD12 Carrier Demodulator, Validyne Model DP-15 Pressure Transducer, Perkin Elmer MDA-1100 Mass Spectrometer, and a pressure breathing tester/trainer. Following the development of the draft SOPs, KLSI personnel validated the procedures by monitoring Government personnel while various equipment tests were accomplished. This procedure was used to familiarize the Government personnel with the SOPs, and to ensure that the procedures were complete and accurate. In addition, staff training for Government personnel was provided in equipment operation and general procedures for oxygen regulator testing and manned rapid decompression tests.

l. Technical support was provided for the following high altitude system testing: the use of the CRU-93 Aircrew Oxygen Regulator with chemical defense equipment, the Advanced Breathing Regulator (ABR) 200 Oxygen Regulator, the NASA/ASFSI Oxygen Regulator (Model ABR 250-G6), the B-1 Molecular Sieve Oxygen Generating System (MSOGS) and the Intertechnique Aircrew Respirator. The high altitude support effort was continued under Task Order No. 10, Contract F33615-92-C-0018

m. The management plan was extended by six months to include the additional tasks and milestones required to develop an improved inflation time ATAGS. An additional program management review was held to review data and endure coordination with USAF personnel. All decisions regarding the design and fabrication of the improved inflation time ATAGS were based on discussions with the Crew Technology Division, Task Order Technical Monitor and personnel from the Human Systems Program Office.

n. The following areas were evaluated by the David Clark Co. to develop concepts and suit design changes that would improve the suit inflation time.

(1) The suit to aircraft connector was evaluated to determine the effect of removing the check valves. Suit back pressure (inlet hose pressures upstream from the connector) tests were conducted at flow rates of 6 to 18 Cubic Feet per Minute (CFM). The removal of the check valves from the connector reduced the back pressures by an average of 46%. A reduction in hose back pressure might be expected to translate to improve air flow into the suit and should decrease the suit inflation time. These tests were conducted using inflation hose sections with the air flow through the suit inflation hose dumping to ambient. When inflation time testing of the integrated suit was conducted, the removal of the check valves did not appreciably improve the suit inflation time. The other modifications to improve the suit inflation time--a revision of the Trilock-lock and spring configuration in the inflation hose and the extension of the Trilock air manifold in the suit--were incorporated into the improved inflation time ATAGS. These modifications were moderately successful improving the air flow into the suit. Mannequin testing conducted by KLSI showed that the air flow into the improved inflation time suit reached maximum flow rates of approximately 21 CFM while the maximum flow rate in the standard ATAGS was approximately 19 CFM. The maximum unrestricted (flow to ambient) flow rate from the ALAR high-flow anti-G suit inflation valve was approximately 22 CFM; thus, the air-flow into the Improved Inflation Time ATAGS is nearly equal to the maximum capability of the valve. Inflation time tests conducted by KLSI confirmed that the improvement in air flow in the Improved Inflation Time ATAGS did not translate to greatly improved overall suit inflation times. As an additional effort to improve air flow through the suit, the "necked down" areas where the abdominal bladder connects to the legs were enlarged. The David Clark Co. fabricated a prototype bladder to investigate this concept and found that no significant improvement in the overall inflation time was realized.

(2) Reduced Bladder Volume. The David Clark Co. developed an experimental prototype leg section of the ATAGS to evaluate a reduced volume concept in which the bladder would only cover 50 to 75% of the circumference of the limb. These partial coverage bladders

were evaluated on a mannequin leg section to determine the pressure transfer characteristics. One concept used two opposing bladders with each bladder covering 25% of the limb circumference. This concept was called the "50/50" bladder. Mannequin testing of the 50/50 bladder demonstrated pressure transfer characteristics that were equivalent to the full coverage ATAGS. This concept was reviewed by both KLSI and USAF personnel during an ATAGS design review on 31 May 1995. When the prototype suit was fitted on a human subject it was found that the suit bladders would balloon and caused an uneven pressure transfer. Further investigation of the concept showed that to apply uniform pressure to the mannequin leg section, the 50/50 bladder suit had to be very tightly fitted around the circumference of the leg. For the manned testing, it was not possible to achieve the degree of tightness required and still maintain the capability to easily don and doff the suit. Based on these findings, further work on the 50/50 reduced bladder volume design was discontinued.

(3) Optimized Restraint Layer Easement. The David Clark Co. conducted an evaluation of the design and sizing of the restraint layer of the suit to determine if any excess fabric could be removed. This tightening of the restraint layer would restrict bladder growth and decrease the bladder volume. The results from this evaluation determined that the basic design of the suit restraint layer was nearly optimum and no additional adjustments could be accomplished.

(4) Optimized Take-up Lacing. The David Clark Co. conducted an evaluation to determine if extended leg take-up lacings could be used to selectively tighten the restraint layer and reduce the suit volume. This evaluation showed that a slight reduction might be achieved by tightening the restraint layer in the knee area. Unfortunately, the extension of the lacings down the side of the knee area caused a loss of knee mobility and was not acceptable for an operational suit.

(5) Low Elongation Restraint Layer Fabric. The Advanced Materials ATAGS effort established that the use of staple fiber Nomex would reduce suit volumes by approximately 15 percent; thus, the staple fiber fabric was used in the improved inflation time ATAGS. Tests conducted by KLSI showed that the size 8 Decreased Inflation Time ATAGS volume was approximately 27 liters. The volume of the standard configuration size 8 ATAGS averages approximately 30 liters. The use of the low elongation, staple fiber Nomex did contribute to a small reduction in suit volume; however, the overall effect did not contribute to a significant reduction in suit filling time.

o. The David Clark Co. provided modified drawings to support the development of patterns and other information needed to fabricate a Reduced Inflation Time ATAGS. The drawings incorporate the following modifications that were incorporated into the final design of the Reduced Inflation Time ATAGS: the use of a two spring inlet hose anti-block, the extended Trilock-lock and springs into the legs of the suit, and an expanded restraint pass through hole for the inflation hose. Changes in the restraint layer material did not require alteration of the patterns or drawings.

p. Additional Efforts. In addition to the basic development of the Decreased Inflation Time ATAGS, David Clark Co. provided technical support to analyze the inadvertent zipper opening

issues that were identified in both Armstrong Laboratory and David Clark Co. fabricated suits. The suits referred to David Clark Co. for analysis included a David Clark Co. fabricated size 4 ATAGS that suffered a zipper failure during a US Navy test flight and a size 6, laboratory fabricated suit that failed during centrifuge testing. David Clark Co. also conducted an analysis of seam stretches "windowing" that occurred in a size 5 David Clark Co. fabricated ATAGS. The input from the David Clark Analysis of the zipper migration issue provided confirmation that zipper overruns and a zipper slider retention tab was required for the final ATAGS design and that the donning buckles were required as a safety device. The seam windowing analysis confirmed that the ATAGS fabric should be reoriented to improve seam strength.

26.6 Altitude Decompression Research

The contractor shall conduct hypobaric decompression research using a human subject protocol designed investigate the effectiveness of exercise-enhanced prebreathe relative to resting prebreathe in the prevention of decompression sickness symptoms (DIN A005, DIN A014, DIN A016). In support of human-use decompression research, provide an echo-imaging technician whose duties shall include but not be limited to operating a Hewlett Packard SONOS Phased Array Imaging System, performing cardiac and vascular imaging, providing general support for subjects before, during and after experiments, and recording and entering research data.

Accomplishments

Scientific and technical activities were provided in support of the protocol "Effect of Prebreathe with 100% Oxygen while Exercising on Incidence of Decompression Sickness (DCS)" (AL ACHE #89-25B, addendum, 2Jul92; formerly USAFSAM ACHE #89-25, 15May90). Accomplishments of this protocol are listed in Section 11, *Effects of Prebreathe while Exercising on DCS.*

26.7 In-House Development of Experimental Life Support Equipment

The contractor shall provide the required additional skilled labor in the LSEDL to maintain a production level of at least two completed current configuration ATAGS per month. This will augment and support the work being accomplished under the fixed (CLIN I) portion of the contract.

The contractor shall develop the capability in the LSEDL to utilize advanced materials, such as breathable fabric, in fabricating ATAGS or other items of LSE. The contractor shall provide the necessary skills, materials, equipment, and/or any special training required to develop this capability.

The contractor shall deliver an additional 10 items of experimental LSE such as ATAGS or COMBAT EDGE jerkins in one of the configurations or incorporating one or more of the technologies listed below:

1. Current configuration ATAGS

2. Modified ATAGS profile

3. Decreased volume ATAGS

4. Advanced Materials ATAGS

The contractor shall provide the required additional skilled labor in the LSEDL to fabricate or modify small items of experimental LSE (up to 5 per month).

Accomplishments

KLSI assigned a soft-goods fabrication technician and provided administrative and management support to produce 24 ATAGS, develop technology to use advanced materials in ATAGS production, and fabricate/modify other items of life support equipment. This task successfully supported the LSEDL in meeting requirements for both the quantity and quality of equipment fabricated and repaired. During this effort, KLSI accomplished the following items:

a. Production of ATAGS. During the period of this task, the LSEDL production of ATAGS totaled 29 suits. This number included suits of all sizes except ATAGS size 3. Included in this number were 3 experimental ATAGS. Two suits were manufactured with knee holes and one size 8 suit was fabricated with restraint and bladder modifications to reduce the volume. During the year, modifications to the ATAGS design were accomplished incorporating the improvements developed under Task Order 004 by the David Clark Co.

b. Advanced Materials. In October 1994, the KLSI LSEDL engineer/manager visited the David Clark Co. to review the fabrics and fabrication techniques used in the advanced materials ATAGS and the advanced materials COMBAT EDGE garment. Advancements in ATAGS fabrication technology have included the use of a modified inflation hose and an abdominal bladder manifold system to improve the suit inflation time. These improvements were accomplished without resorting to the use of stiff inflation hoses or hard plastic connectors which were found to interfere with the fit of the aircrew parachute harness. The leg zippers of the ATAGS were changed from a Talon zipper to a zipper manufactured by Scovill. The Scovill zipper meets the same Military Specification as the Talon zipper and is much easier to zip and unzip. In addition, a new donning/restraint buckle was evaluated and incorporated into the ATAGS design. In the event of a leg zipper failure, the donning/safety buckle provides a back up restraint system to prevent the suit from ballooning and possibly interfering with control of the aircraft.

c. Experimental/Advanced Design ATAGS and other Life Support Equipment.

(1) ATAGS produced in the LSEDL included 12 suits which incorporated the modified inflation hose and the improved zippers. In addition, an experimental ATAGS was fabricated with a larger crotch area in an attempt to improve hip and thigh mobility. This modification did not significantly improve mobility and did not provide adequate restraint of the abdominal bladder. In

response to a finding that the larger sized ATAGS were slow inflating, a size 8 ATAGS (large circumferences, regular length) was modified by using both internal and external bladder restraints. This effort was successful in reducing the volume of the suit by approximately 15 percent; however, the addition of the additional restraints made the suit heavier and stiffer. Other experimental design efforts included the addition of donning/safety buckles to the ATAGS. These experimental suits were used in testing to establish the location and strength requirements for the restraint buckles. The experimental suits were modified a number of times with the buckles located in various positions until an effective design was established. This information was provided to the David Clark Co. and was incorporated into the ATAGS fabricated under Task Order 004.

(2) The LSEDL developed patterns, seaming techniques, and fabricated an oxygen hood which could be used as a replacement for the Intertechnique oxygen hood in altitude chamber research programs. The hood development was successful; however, an oxygen regulator that was compatible with the system was not available in-house. With the purchase of a suitable oxygen regulator and connections, this in-house fabricated system could provide a low cost replacement for the Intertechnique oxygen hoods.

d. Fabrication of Other Life Support Equipment. Multiple items of life support equipment were fabricated and repaired. This effort included the modification of 4 CSU-13B/P anti-G suits for female centrifuge subjects and the modification of 2 CSU-13B/P anti-G suits for female F-16 pilots. Several other G-suits were repaired including a Swedish suit that was used in a centrifuge evaluation of a new G-protection system. Two restraint vests for miniature swine were fabricated and 6 Intertechnique oxygen hoods were repaired. Several parachute harnesses were repaired/modified for cockpit integration studies. In addition, a number of fluid filled boot insoles were developed. These insoles were to be used in a flight evaluation to determine the amount of rudder pressure that is applied by pilots during their anti-G straining maneuver. Other minor efforts included the repair of flight suits and other equipment for the Cockpit Integration Laboratory.

26.8 Altitude Decompression Research

The contractor shall conduct hypobaric decompression research using a human subject protocol designed to investigate the effect of isotonic versus isometric exercise relative to the incidence of decompression sickness symptoms (A005, A016). In support of human-use decompression research, provide an echoimaging technician whose duties shall include but not be limited to operating a Hewlett-Packard Ultrasound Imaging System, performing cardiac and vascular imaging, providing general support for subjects before, during and after experiments, and recording and entering research data.

Accomplishments

Scientific and technical activities were provided in support of the protocol "Effect of Exercise on Altitude Decompression Sickness" (AL ACHE #91-07, 25Feb91; addendum to ACHE 90-32 and

87-15). Research reports (DIN A005, DIN A009, DIN A010, and/or DIN A016) from this effort include:

Fischer MD, Wiegman JF, McLean SA, Olson RM. Evaluation of four different exercise types for use in altitude decompression sickness studies. 30th Annual SAFE Symposium Proceedings. 1993;102-5. (see Section 11 for abstract)

Olson RM, Pilmanis AA, Webb JT. Decompression sickness risk and the mode of exercise at altitude. (Abstract) Aviat. Space Environ. Med. 1995;66:491.

Abstract: "INTRODUCTION. It has been known since World War II that exercise at altitude increases the incidence of decompression sickness (DCS); however, data on the effect of specific types of exercise at altitude on DCS is lacking. For example, is exercise without motion (isometric), as in straining, as likely to induce DCS as exercise involving motion (isotonic)? METHODS. Each of 26 healthy male subjects was exposed, while resting, to FL295 for 4 hours or until DCS occurred at which time he was brought to ground level. If the subject developed DCS, he was exposed to a series (at least a week apart) of stepwise, decreasing altitudes from FL295 to FL200 until he was symptom free. Then the subjects performed isometric arm, isometric leg, isotonic arm, and isotonic leg exercises at approximately 15% maximal oxygen consumption. These were done on separate occasions at least a week apart at the symptom-free altitude. It was postulated that the occurrence of DCS at this altitude (tolerance altitude) would be due to the added stress of exercise. RESULTS. Isotonic arm and leg exercise and isometric arm and leg exercise induced DCS in 48%, 33%, 37% and 33% of the subjects respectively. No statistical differences were found. CONCLUSIONS. The mode of exercise while at altitude does not appear to be a major factor in determining DCS risk."

Pilmanis AA, Meissner FW, Olson RM. Left ventricular gas emboli in six cases of altitude-induced decompression sickness. Aviat. Space Environ. Med. 1996;67:1092-6. (see Section 11 for abstract)

Pilmanis AA, Olson RM, Fischer MD, Wiegman JF, Webb JT. Exercise-induced altitude decompression sickness. Aviat. Space Environ. Med. [In Peer Review].

Abstract: "INTRODUCTION. It has been known since World War II that exercise at altitude increases incidence of decompression sickness (DCS). However, data on the effects of specific exercise types at altitude are lacking. This research focused on the relative hazards of exercise without motion (isometric, straining) versus dynamic exercise involving motion. The study also compared arm versus leg exercise. METHODS. Thirty-two healthy male subjects were exposed, while resting, to 29,500 ft (8,992 m) for 4 hours or until DCS occurred, at which time they were brought to ground level. If the subject developed DCS on this exposure, he was exposed in successive months to lower altitudes, using the same procedure, until the subject was free of symptoms for the 4 hour exposure. At this symptom-free altitude, as low as 20,000 ft (6,096 m), the subject performed isometric arm, isometric leg, dynamic arm and dynamic leg exercises, each during separate exposure months, at approximately 15% of maximal oxygen consumption. Precordial venous gas emboli (VGE) were monitored every 15 min during each exposure with a

Hewlett-Packard SONOS 1000 Echo Imaging System. RESULTS. Dynamic arm, dynamic leg, isometric arm, and isometric leg exercise induced DCS in 50%, 38%, 41% and 31% of the subjects respectively. VGE incidence varied from 47-66%. No significant differences in DCS or VGE were found. CONCLUSIONS. Under our test conditions, there was no difference between dynamic and isometric exercise in eliciting DCS. Exercise during exposure to the symptom-free altitude for 4 hr produced a 40% incidence DCS."

26.9 Oxygen Generating Systems Research

The contractor shall analyze data collected from laboratory evaluations of developmental and prototype molecular sieve oxygen concentrators and oxygen monitoring devices, and field tests of operational OBOGS units; and provide technical reports documenting results and performance. (A016)

The contractor shall provide specialized technical advice on the design and shall evaluate performance of new generation hybrid oxygen systems for aircrew and medical applications, using Government furnished equipment (GFE) to demonstrate the technical feasibility of generating and liquefying oxygen from a molecular sieve oxygen generating system (MSOGS) and shall provide a report on their performance. (A016)

During the course of above research and development (R&D) activities, the contractor shall provide general technical advice and consultative support to other R&D efforts. (Such efforts shall include but not be limited to technology transfer of Molecular Sieve Oxygen Concentrator (MSOC) and the USAF and tri-service/joint research and development programs involving OBOGS.)

Accomplishments

The Flight Evaluation of the B-1B OBOGS required that humidity, temperature, and pressure data be collected at the inlet and outlet of the B-1B OBOGS heat exchanger. It has been suspected that excessive temperature and humidity at the oxygen concentrator inlet are contributing factors toward the B-1B OBOGS failures. The failures result in the breakdown of zeolite molecular sieve pellets which leads to a condition known as "dusting." Presently, a downstream particulate filter captures any dust produced by the system. This problem has reduced the system operational life to about 150-450 flight hours. The original OBOGS specification for the B-1B stated that the system operational life should be 6,000 flight hours.

A planning meeting occurred on 26-28 Apr 94 at Dyess AFB, TX. During the meeting Westinghouse described the operation of the instrumentation package. Also, the instrumented OBOGS was installed on B-1B #60109. Procedures were finalized for transferring the flight data from Dyess AFB to Brooks AFB.

During the task period data from thirteen sorties were reduced, plotted, and analyzed. Quick-look reports were written and submitted to the participating organizations. The data indicated that some of the aircraft sensors were not functioning properly.

Major Hybrid Oxygen System (HOS) components were installed in Building 161. Calculations were accomplished to size three HOS plenums. Vacuum and compressed air lines were installed.

The detailed process flow and electrical schematics for the system were implemented. Concurrently, the data acquisition and control software was developed with fail safe features that considered different modes by which the system should be shut down. These features minimized the likelihood of operator error.

Repairs to the HOS vacuum vessel were made. A malfunctioning air directional valve was extracted, repaired and reinstalled in the system. While the vessel was "open", two temperature sensors were made operational by reconnecting their electrical leads. After the vessel was reassembled, the operational vacuum could not be attained. Leaks had developed that could not be detected without special leak detection equipment, although on two occasions, such equipment was available for a short time. During this time, prominent leaks were located; but by the time the repairs were completed, the loan period for the special equipment had expired and there was no way to continue checking the integrity of the vacuum vessel. A request was voiced to purchase the necessary leak detection equipment but due to a lack of funds, no action was taken. Without a vacuum of $1x10^{-5}$ Torr, heat is transferred to the cryogenic subsystem and liquefaction does not occur at the defined pressure of three atmospheres.

The HOS major components were removed from Building 161 on three occasions and stored due to problems with the new ceramic floor. Misapplication of sealants and the resulting solvents used in preparation for re-sealing corroded the systems piping. In Apr 95 the system was moved back into the building and assembly of the system was re-initiated. The culmination of delays encountered with the Hybrid Oxygen System (HOS) project caused the system to never achieve operational status. A shake down testing of the system was in progress when the project was terminated.

General technical and consultative support over a wide range of topics concerning OBOGS research, development, design, flight qualification, man-rating, performance, maintenance, physiology, and chemical contamination issues was provided. Several programs supported were: High Performance MSOGS, tri-service OBOGS programs, and existing and future aircraft OBOGS systems.

A preliminary design for the B-1B OBOGS Depot Maintenance Facility at Building 1055, OC-ALC, Tinker AFB, Oklahoma was completed and a final briefing was presented to Tinker AFB officials. During this effort a facility master plan was developed, major equipment items were identified, proper repair flow was determined, and altitude chamber modifications were designed.

The KLSI Technical Specialist had several meetings with Tinker AFB officials during the course of this effort. The Technical Specialist traveled to Hill AFB, UT to take measurements on the proposed chamber. Also, the Technical Specialist visited the current B-1B OBOGS contractor maintenance facility at Hermetic Aircraft International Corporation, Holtsville, NY.

OC-ALC made a decision to construct the facility. Major facility equipment items were ordered. An Armstrong Laboratory molecular sieve activity tester will be fabricated for the facility. The final report for the preliminary design effort is in preparation. The next phase of the effort is the facility detailed design. The payoff will be significantly reduced costs for maintaining the B-1B OBOGS. Potentially, the facility could be used to maintain all U.S. military OBOGS systems.

Preliminary sizing of a High Performance Molecular Sieve Oxygen Generating System (HP-MSOGS) for the Advanced Hybrid Oxygen System (AHOS) was accomplished. Two laboratory prototype systems were constructed and tested. A large scale laboratory prototype device called the 65MS HP-MSOGS was built with in-line zeolite and carbon molecular sieve beds. Also, a small scale prototype device called the 5L Annular HP-MSOGS was fabricated with an annular bed geometry. Data collected from these two devices will assist in designing the final prototype HP-MSOGS. Several reviews of the 65 MS and 5L Annular HP-MSOGS engineering drawings were accomplished. The drawing packages were completed and delivered to the base fabrication shop. Parts for the 65 MS HP-MSOGS and 5L Annular HP-MSOGS were ordered.

The KLSI Technical Specialist provided technical support for the AHOS program. The specialist discussed AHOS objectives, plans, and progress with CFTS personnel. Weekly AHOS Integrated Product Team meetings were attended. Technical information was exchanged with Creare Inc., the company that will develop the cryogenic liquifier.

The KLSI Technical Specialist attended the F-22 Life Support System (LSS) design reviews. At the reviews, issues related to the development of the F-22 breathing system (OBOGS, BRAG valve, Emergency Oxygen System, etc.) were discussed.

F-22 OBOGS developmental test data were reviewed. The data were analyzed and comments were prepared for submission to the F-22 SPO. This information was coordinated with CFTS, CFTF, and HSC/YA personnel. The goal of this effort is to determine the accuracy of the oxygen monitor and the low oxygen warning circuitry.

Proposed changes to the F-22 OBOGS oxygen schedule were reviewed. The KLSI Technical Specialist discussed the changes with CFTS personnel.

Proposed B-2 OBOGS engineering modifications were reviewed at the request of the B-2 SPO. The KLSI Technical Specialist attended a meeting at the B-2 SPO, Wright-Patterson AFB, OH to discuss the proposed changes with SPO and contractor personnel.

The KLSI Technical Specialist reviewed the protocol for the F-16 OBOGS Flight Qualification and Man-Rating effort. Also, the Technical Specialist met with OO-ALC, F-16 SPO, Lockheed, and Litton ILSD personnel and presented an overview of the proposed F-16 OBOGS flight qualification and man-rating test protocol. The specialist conducted acceleration tests on the F-16 OBOGS, oxygen monitor, and regulator. Also, data collected during the man-rating effort were reviewed. The results of the effort were discussed with Armstrong Laboratory personnel.

The KLSI Technical Specialist attended a meeting at the F-15 SPO, Robbins AFB, GA concerning the retrofit of F-15A/D aircraft with OBOGS. Three OBOGS designs were discussed. A life cycle cost analysis will be conducted by the airframe manufacturer to determine the most cost effective design.

At the request of ASC the KLSI Technical Specialist reviewed proposed changes to the B-1B OBOGS technical orders and job guides. These documents are being modified to incorporate a new oxygen analyzer test. The test would be conducted during operational checkouts of the B-1B OBOGS.

The KLSI Technical Specialist assisted Armstrong Laboratory personnel in determining test parameters for the B-1B AERP chemical contaminant study and man-rating. A test plan for the chemical contaminant study was prepared. The specifics of the chemical contaminant test plan and test procedures were discussed with Armstrong Laboratory and Dugway Proving Ground personnel. Also, pressures, temperatures, and modes of operation for the man-rating effort were discussed. Several design approaches for the modified AERP were discussed. Also, the work plan for this effort was prepared.

Information and software related to the Molecular Sieve Activity Tester were submitted to the U.S. Navy, Naval Air Warfare Center, Warminster, PA. The Navy and the Air Force are interested in incorporating this device into their OBOGS depot level maintenance programs. Presently, the Navy is fabricating a tester. Also, the Armstrong Laboratory is fabricating a tester for the B-1B OBOGS Depot Maintenance Facility, OC-ALC, Tinker AFB, OK.

The draft test plan for the oxygen sensor test and evaluation effort was reviewed and revised. The design of the experimental apparatus was accomplished.

Technical consultation was provided in support of the Armstrong Laboratory and Arbor Research Corporation High Performance Molecular Sieve Oxygen Generating System (HP-MSOGS) Corporation Cooperative Research and Development Agreement (CRADA). The one year CRADA concluded on 23 Sep 94. The HP-MSOGS was successfully scaled-up to a product flow rate of approximately 5 liters/minute. Also, the oxygen recovery of the HP-MSOGS was significantly increased. Further development of the HP-MSOGS technology will be accomplished at the Arbor Research Corporation, Ann Arbor, MI facility. The draft final report for the effort was reviewed.

Final reports titled "Engineering Qualification and Human Performance Testing of the F-15E Molecular Sieve Oxygen Generating System (MSOGS)" and "Engineering Qualification Testing of the Oxygen Generating and Distribution System (OGADS)" were finalized and submitted into the Armstrong Laboratory clearance process.

Research reported (DIN A005, DIN A009, DIN A010, and/or DIN A016) from this effort includes:

Ikels KG, Miller GW. Molecular Sieves, Pressure Swing Adsorption, and Oxygen Concentrators. AGARDograph 286, Chapter 6. 1996:34-41.

Abstract: "The development of on-board oxygen generation systems has undergone several transformations, but at the present time, has centered on pressure swing adsorption (PSA) using molecular sieves. While other oxygen generation techniques have been flight tested, the only OBOGS technology currently flying in production aircraft is based on molecular sieves and PSA. This is due to MSOGS simplicity, lower energy consumption, reduced maintenance costs, and long life, when compared to other OBOG systems. Use of MSOGS technology in military aircraft eliminates the logistics tail associated with liquid oxygen, improves safety, reduces aircraft turnaround time, and extends mission duration (which can be limited by oxygen storage capacity), and significantly lowers operational costs. This chapter reviews the chemical and physical basis for molecular sieve separation of air using pressure swing adsorption, and describes the important factors in the design of molecular sieve oxygen concentrators."

26.10 High Altitude Applied Research and Equipment Evaluation

The contractor shall conduct and provide support for test and evaluation of life support items such as positive pressure breathing systems or components, oxygen regulators, escape breathing apparatus, and aeromedical equipment; provide test data and information, including methods of analysis, test results, and conclusions, necessary for development of final test reports (A005, A019).

The contractor shall provide software support for data acquisition and analysis for testing conducted; be responsible for software development and testing, as well as all documentation of software: developmental, test, and source code (DIN A007).

The contractor shall support hyobaric decompression research using a human subject protocol designed to investigate the impact of altitude exposure above 30,000 feet or multiple daily exposures at lower altitudes on incidence of DCS; provide an echoimaging technician whose duties shall include but not be limited to: 1) operating a state of the art ultrasound imaging system; 2) performing cardiac and vascular imaging; 3) providing general support for human subjects before, during and after experiments: and 4) recording and entering research data (DIN A005, DIN A016).

Accomplishments

Technical and Echo-imaging equipment support activities were provided for hypobaric research chamber protocols active during the period of performance and reports (DIN A005, DIN A009, DIN A010, and/or DIN A016) generated with the data gathered (DIN A003 and DIN A011) are listed in Section 11.

Research reports from the test and evaluation effort include (DIN A005 and DIN A019):

Hade EW, Fenner JE, Jr. Development of a computerized breathing simulator to simulate and reproduce human respiration patterns. 32nd Annual SAFE Symposium Proceedings. 1994:57-61.

Abstract: "The combination of continuously improving aircraft performance and more demanding missions places increased physiologic burdens on aircrew members. For crew members to operate above 50,000 feet, protection must be provided against the increased likelihood of hypoxia and decompression sickness. State-of-the-art personal equipment, including oxygen generation systems and regulators, must be tested and evaluated during the course of their development This requires the use of specialized, unique test equipment including breathing simulators. Existing single lung simulators used to evaluate aircrew breathing systems have fixed, periodic breathing profiles. Because human respiration is more variable with respect to rate and depth, variably programmable simulators must be employed to adequately test aircraft oxygen systems. Additionally, these simulators must be capable of operating at altitudes exceeding 50,000 feet. The Computerized Breathing Simulator (CBS), developed under contract for the Air Force and Navy, is a portable system which will simulate standard air-flow profiles that realistically impose human respiration patterns or which will reproduce actual human breathing patterns which have been previously saved. This system was designed to simulate \reproduce human respiratory flow profiles during workloads and stressful conditions encountered during high-altitude flight and can be used to quantitatively test and evaluate the dynamic response of oxygen/air systems and subsystems to 70,000 ft. pressure altitude. This paper describes specialized hardware and software "components" which were integrated into the CBS to meet system requirements."

Research reports from the echoimaging effort include (DIN A005 and DIN A019):

Hasser CJ, Nering JD, Pilmanis AA, Beene D, Webb JT. Teleoperated echocardiography for hypobaric aircrew research. (Abstract) Aviat. Space Environ. Med. 1996;67:666.

Abstract: "INTRODUCTION. Aircrew decompression sickness (DCS) research requires the use of echocardiography to detect venous gas emboli (VGE) in the heart of human subjects while exposed to simulated altitude in a chamber. The traditional method of detecting VGE, employing inside observers to manipulate the echo-imaging probe is not feasible at the higher altitudes due to increased DCS risk to the inside observers and the cost-prohibitive nature of alternate solutions. NEW METHOD. Requirements for data from such high altitude research led to the development of a Puma 260 remote manipulator system that allows the Echo-Imaging Technician to manipulate the probe from outside the chamber via a robot control computer and manual control box (teach pendant) located outside the chamber. EVALUATION. The teleoperated probe is being used during an on-going study at 35,000 ft. The preliminary echo-imaging results from that study show regions of the heart and VGE with good clarity. Slides of teleoperated and inside observer-operated echocardiography sessions show what appear to be equivalent images. CONCLUSIONS. The teleoperated system enables tests to be run at previously impractical

altitudes and yield echo-imaging results which closely resemble those obtained via inside operators at lower altitudes."

26.11 Neurochemical Regulators of the Circadian Clock

The contractor shall characterize the circadian patterns of expression of : 1) the amino acid receptors species. NMDAR1, NMDAR2b, GluR1, GluR2, and GluR4, and 2) the serotonin receptor species. 5HT1A, and 5-HT7 in the hamster and rat SCN. These studies will be conducted on SCN micropunches using the quantitative reverse transcriptase polymerase chain reaction (RT-PCR) technique using procedures developed and equipment supplied by the Government. (DIN: A004, A005, A007, A010, A016, A017, A019)

The contractor shall determine the effects of electrical stimulation of the median and dorsal raphe nuclei on (1 the phase of the free running activity rhythm in hamsters, and 2) on the magnitude of light-induced phase shifts of the free running activity rhythm in hamsters. Activity rhythms will be monitored as wheel running activity of hamsters maintained under constant darkness using facilities and equipment supplied by the Government. (DIN: A004, A005, A007, A010, A016, A017, A019)

The contractor shall determine the effects of local infusion into the hamster and rat SCN of antisense oligonucleotides on 1) phase shifts of the circadian activity rhythm induced by electrical stimulation of the median raphe nuclei, and 2) on light-induced phase shifts, which appear to be modulated by serotonin. The contractor shall monitor the effectiveness of the antisense oligonucleotide treatment by western analysis using antisera provided by the Government, in collaboration with colleagues at the Scripps Research Institute and the National Institutes of Health, to detect changes in receptor protein after antisenseoligonucleotide infusion. (DIN: A004, A005, A007, A010, A016, A017, A019).

The contractor shall deliver a Final Report in a form suitable for publication in a peer-reviewed scientific journal. This report will summarize all test results obtained and conclusions drawn from the research effort. In addition, the contractor shall deliver to the Government laboratory all laboratory notebooks, autoradiograms, histological material, computer data files, computer printouts, graph, drawings, calculations and other physical products of the research activity. (DIN: A004, A005, A007, A010, A016, A017, A018, A019)

The contractor shall conduct meetings and reviews: (DIN: A005, A010, A016, A019)

Accomplishments

Meetings and reviews were held on a regular basis. Research reports (DIN A005, DIN A009, DIN A010, and/or DIN A016) from this effort include:

Erlander MG, Foye PE, Danielson PE, Carson MJ, Cagle M, Gannon RL, Rea MA, Sutcliffe JG. Cloning of differentially expressed genes within hamster suprachiasmatic nucleus (SCN) in response to light entrainment. (Abstract) Soc. Neurosci. 1994;20:162. [see Requirement 15.2]

Gannon RL, Cato MJ, Kelly KH, Armstrong DL, Rea MA. GABAergic modulation of optic nerve-evoked field potentials in the rat suprachiasmatic nucleus. Brain Res. 1995;694:264-70.

Abstract: "The suprachiasmatic nuclei (SCN) at the base of the hypothalamus are known to be the site of the endogenous circadian pacemaker in mammals. The SCN are innervated by the retinohypothalamic tract, which conveys photic information to the SCN. GABA is one of the most abundant neurotransmitters in the SCN, and has been implicated in the modulation of photic responses of the SCN circadian pacemaker. This study sought to examine the effect of GABAergic compounds on optic nerve-evoked SCN field potentials recorder in rat horizontal hypothalamic slices. The GABAa agonist muscimol (10 μM) potentiated SCN field potentials by 23%, while application of the GABAa antagonist bibubulline (10 μM) inhibited SCN field potentials by a similar amount, (22%). Conversely, the GABAb agonist baclofen (1.0 μM) inhibited SCN field potentials by 48%, while the GABAb antagonist phaclofen (0.5 mM) augmented SCN field potentials by 62%. Recordings performed at both day and night times indicate that there were no qualitative day-night differences in GABAergic activity on SCN field potentials. This study concludes that, in general, GABAa activity tends to increase, and GABAb activity tends to decrease the response of SCN neurons to optic nerve stimulation."

Gannon RL, Rea MA. Serotonergic mixed 5HT1A agonists/antagonists potentiate light-induced phase shifts of hamster circadian activity rhythms. Soc. Neurosci. 1995;21:180.

Abstract: "The effects of systemically injected 5-HT1A and 5-HT7 antagonists on light-induced phase shifts of hamster circadian wheel running activity were evaluated. Both 5-HT1A and 5-HT7 receptors have been implicated in the regulation of the circadian pacemaker located in the suprachiasmatic nucleus of rodents. Hamsters were maintained under conditions of constant darkness, and their free running activity rhythm was monitored. Antagonists were injected i.p. from 45-105 min prior to a 10 min pulse of light (20 lux) at CT19, a stimulus which is known to phase advance circadian rhythms by 1-2 hr. The mixed 5-HT1A agonists/antagonists BMY7378 and NAN-190 potentiated light-induced phase advances by as much as 6 hr. Neither the 5-HT1A antagonist (+)WAY100135 nor the putative 5-HT antagonists ritanserin and clozapine had any effect on light-induced phase shifts. BMY7378 also had no effect when injected directly into the region of the SCN. These and previous data suggest that BMY7378and NAN-190 may potentiate light-induced phase advances by inhibiting raphe serotonergic cell firing through the activation of somatodendritic 5-HT1A receptors, and removing an inhibitory influence of serotonergic afferent input to the SCN. However, the effects of these two compounds could not be attenuated by spiperone or (+)WAY100135, antagonists at the somatodendritic 5-HT1A receptors in other species. Although the site of action for BMY7378 and NAN-190 remains to be identified, these compounds illustrate that mixed 5-HT1A agonists/antagonists may prove to be a new class of highly efficacious chronopharmaceuticals."

Gannon RL, Rea MA. Twelve -hour phase shifts of hamster circadian rhythms elicited by voluntary wheel running. J. Biol. Rhythms. 1995;10:196-210.

Abstract: "Running in a novel wheel can serve as a nonphotic zeitgeber to entrain or phase shift circadian rhythms in hamsters. In this study, hamsters were entrained to a light:dark schedule of 14:10 h ,but had no access to running wheels. At four different phase points of the light cycle, hamsters were transferred to constant darkness and provided with running wheels. All hamsters began running shortly after transfer and were allowed to continue running at their own volition. Approximately 20% of the hamsters transferred at zeitgeber time (ZT) 23 (ZT 12 = lights out) ran more than 4 h after transfer and showed phase advances of the circadian activity rhythm by as much as 15 h, while hamsters that ran less than 4 h on average did not phase shift. A similar result was observed for hamsters transferred at ZT 2. Hamsters transferred at ZT 5 and 8 also did not phase shift if they ran less than 4 h, although the relation between longer runs and phase shifts became less evident. A sustained run in excess of 4 h appeared to be associated with large phase advances. These results show that under certain conditions, a single sustained bout of wheel-running activity is capable of phase shifting the circadian pacemaker by more than 12 h."

Rea MA, Barrera J, Glass JD, Gannon RL. Serotonergic potentiation of photic phase shifts of the circadian activity rhythm. NeuroReport. 1995;6:1417-20.

Abstract: "Recent evidence suggests that serotonin may function to regulate the sensitivity of the circadian clock to the resetting effect of environmental light. Here we report that systemic administration of NAN-190, a drug that acts at both postsynaptic and somatodendritic serotonin receptors, potentiates light-induced phase shifts by as much as 250%. The effects of the drug are dose-related and are significant at light intensities between 0.2 and 200 lux. It is proposed that drugs with pharmacological properties similar to NAN-190 may prove useful as chronobiologics to adjust the sensitivity of the circadian system to natural 'zeitgebers'."

Rea MA, Cato M, Michel AM, Gannon RL. Lesions of the intergeniculate leaflet block serotonergic potentiation of light-induced phase advances of hamster circadian activity rhythms. (Abstract) Soc. Neurosci. 1995;21:179. [see Requirement 15.2]

Weber ET, Gannon RL, Rea MA. cGMP-dependent protein kinase inhibitor blocks light-induced phase advances of circadian rhythms in vivo. Neurosci. Letters. 1995;197:227-30.

Abstract: "The suprachiasmatic nucleus (SCN) contains the primary mammalian circadian clock. Light synchronizes these circadian rhythms through a mechanism involving the release of excitatory amino acids (EAA) and synthesis of nitric oxide (NO) in the SCN. In the current study, we investigated whether cGMP-mediated activation of cGMP-dependent protein kinase (PKG) is associated with light-induced phase shifts of the circadian oscillator. Local administration of the specific PKG inhibitor, KT-5823, significantly attenuated light-induced advances in the phase of activity rhythms when administered during late subjective night (CT 19). Similar treatment at CT 14 had no significant effect on light-induced phase delays. These results are the first to implicate PKG in the biochemical pathway(s) responsible for photic phase advances, and suggest a divergence in biochemical pathways involved in photic phase shifts."

Weber ET, Michel AM, Gannon RL, Scott PA, Rea MA. Local 5HT1A/5HT7 agonists dose-dependently attenuate light-induced phase advances of the suprachiasmatic nuclei in vivo. 5th Meeting Soc. Res. Biol. Rhythms. 1996;50:52. [see Requirement 15.2]

Weber ET, Gannon RL, Michel AM, Gillette MU, Rea MA. Nitric oxide synthase inhibitor blocks light-induced phase shifts of the circadian activity rhythm, but not c-fos expression in the suprachiasmatic nucleus of the Syrian hamster. Brain Res. 1995;692:137-42.

Abstract: "Circadian rhythms in mammals are entrained to the environmental light cycle by daily adjustments in the phase of the circadian pacemaker located in the suprachiasmatic nuclei (SCN) of the hypothalamus. Brief exposure of hamsters maintained under constant darkness to ambient light during subjective nighttime produces both phase shifts of the circadian activity rhythm and characteristic patterns of c-fos protein (Fos) immunoreactivity in the SCN. In this study, we demonstrate that light-induced phase shifts of the ciradian activity rhythm are blocked by intracerebroventricular (i.c.v.)injection of the competitive nitric oxide synthase (NOS) inhibitor N-nitro-L-arginine methyl ester (L-NAME), but not by the inactive isomer, D-NAME. The effects of L-NAME are reversible and dose-related, and are countered by co-injection of arginine, the natural substrate for NOS. While effects on behavioral rhythms are pronounced, similar treatment does not alter the pattern of light-induced Fos immunoreactivity in the SCN. These results suggest that nitric oxide is a component of the signal transduction pathway that communicates photic information to the SCN circadian pacemaker, and that nitric oxide production is either independent of, or downstream from, pathways involved in induction of c-fos expression."

26.12 Female Acceleration Tolerance Enhancement

The contractor shall conduct a developmental effort to improve the fit and function of the CSU-13B/P anti-G suit and the COMBAT EDGE garment for female aircrew. Provide a soft-goods fabrication capability to modify or fabricate CSU-13B/P anti-G suits, ATAGS and COMBAT EDGE GARMENTS to support both research and operational requirements. This program will be associated with an Armstrong Laboratory advanced development (6.3) effort which will rapidly transition the product to the Human Systems Program Office's engineering and manufacturing development program. The materials procured under CLIN I for fabrication of anti-G suits will also be used to fabricate anti-G suits under this task. (DIN: A004, A005, A010 A016, A019, A020, A021)

The contractor shall provide the drawings, instructions and data required to support the rapid transition of the CSU - 13B/P anti-G suit modifications and the COMBAT EDGE Garment modifications to the operational aircrew, (DIN: A004, A005, A010, A016)

The contractor shall conduct a research effort to establish the appropriate modifications and new sizes of the ATAGS to optimize the garment for female aircrew and provide drawings, patterns and fabrication data to support the transition of the garment to engineering and manufacturing development. (DIN: A004, A05, A010, A011, A016, A019, A020, A021)

The contractor shall assign a lead acceleration research scientist with primary responsibility to lead contractor research, development, fabrication and reporting on the female accelerations tolerance enhancement effort. This investigator shall manage any subcontractor development efforts and shall coordinate with personnel from the Armstrong Laboratory and the Human Systems Program Office to establish priorities and determine program direction. Assign a soft-goods fabrication specialist to support the development of modified or new anti-G protective equipment and other items of life support related equipment. (DIN: A004, A005, A010, A011, A016, A019, A020, A021)

Accomplishments

KLSI conducted evaluation of CSU-B/P Fit and compared Male/Female G-Tolerance/Endurance. The data presented here certainly support the efficacy of the Armstrong Laboratory modifications to the CSU-13B/P anti-G suit as adopted in T.O. 14P3-6-121 through greatly improved performance during the +5.0 to +9.0 G_z SACM in females (i.e., those most likely to require the modification). Additionally, the study suggested that, in the sample examined, when fitted with a best-fit anti-G suit, female subjects can endure the +5.0 to +9.0 G_z SACM to the same degree as male subjects. These results are despite the fact that the female subjects examined exhibited significantly lower mean and peak anaerobic power on the Wingate test of muscle power (peak power) and local muscle endurance (mean power).

Citing the difficulty in recruiting subjects in general, and females in particular, for participation in acceleration research of this nature, the authors acknowledge that the small sample size, specifically with regards to the female subjects, is a shortcoming of the present investigation. The comparison of male/female $+G_z$ endurance with regards to more specific muscular strength measurement, in conjunction the gross estimations of anaerobic power utilized here, would be useful in addressing the role of muscular strength in $+G_z$ endurance. Also, the examination male/female $+G_z$ endurance utilizing advanced technology anti-G suits and positive-pressure breathing would be of interest. Finally, if at all possible, increased sample sizes in research of this nature would, of course, be desirable.

COMBAT EDGE and ATAGS fit evaluation. Both the COMBAT EDGE pressure vest (CSU-17/P) and the ATAGS fit a larger portion of the potential female aircrew population than expected. The CSU-17/P vest, when worn under the standard fighter aircraft torso harness, provided a good fit for virtually all subjects. The torso vest tended to act as an outer restraint garment and prevented vest over inflation or ballooning. The vest did not interfere with maximal inspiration or expiration and was reported to be comfortable with no pressure points. In terms of chest circumferences (Skye), the CSU-17/P vest accommodated subjects ranging from 78.7 cm to 101.0 cm. When compared with the population base covered by the 1968 Air Force Survey, the vest, when worn under the torso harness, will fit approximately 85% of the population. Additionally, no alterations appear to be required for the vest to adequately fit this large segment of the population.

Both the currently used anti-G suit, the CSU-13B/P, and the ATAGS were developed to fit the US Air Force male pilot population. As shown during this work, the CSU-13B/P can be modified

to provide the female with equivalent acceleration protection. It was expected that modifications would also be required for the ATAGS to provide a good fit for females; however, this study found that the ATAGS generally provided a good fit for the female subjects and alterations were only needed for individuals with small waist circumferences relative to the hip circumference. The study also indicated that the size 0 (extra-small, short) ATAGS would fit females with statures as small as 152.4 cm, or approximately 80% of the US Air Force female population.

Specific accomplishments.

a. A centrifuge study compared male/female acceleration tolerance/endurance using a +5 to +9G_z Simulated Aerial Combat Maneuver (SACM) acceleration profile, from which investigators evaluated a gender-specific modification of the standard anti-G suit (CSU-13B/P). Results revealed that males were able to perform the SACM significantly ($p<0.05$) longer (169.4 ± 19.1 s) than could the females (101.4 ± 20.1 s) when the modified suit was not used. When the females performed the SACM in the modified suit, they exhibited SACM endurance (202.4 ± 20.1s) equal to ($P>0.05$) that of the males (169.4 ± 19.1 s).

b. The anti-G suit modification was centrifuge-tested by two female fighter pilots, field tested, and incorporated as a Technical Order Safety Supplement, now available for local squadron use by operational aircrew.

c. An anthropometry study of the potential female aircrew population indicated that an additional size (extra-small, short) CSU-13B/P was needed.

d. Three prototypes of the extra-small, short suit were fabricated and centrifuge-tested, and drawings were provided.

e. A fit evaluation of 10 subjects wearing the COMBined Advanced Technology Enhanced Design G-Ensemble (COMBAT EDGE) pressure vest and the Advanced Technology Anti-G Suit (ATAGS) indicated that the vest, as designed, will effectively fit over 80% of the female population. By fabricating an additional smaller (size 0) ATAGS, we were able to fit 5'1" female subjects.

Research reports (DIN A005, DIN A009, DIN A010, and/or DIN A016) from this effort include:

Shaffstall RM. Relaxed tolerance following HSG (High Sustained +G_z). 31st Annual SAFE Symposium Proceedings. 1993:223-6.

Abstract: "Changes in relaxed +G_z tolerance impacts the support required from G protective measures and may affect the capability of the aircrew to re-engage following exposure to HSG. During and post-HSG, simultaneous physiological events which could increase or decrease G-tolerance are activated. METHODS. This study exposed 6 male centrifuge subjects to a GOR (Gradual Onset Rate = 0.067 G/second) acceleration to their subjective G-tolerance limit. Following a rest period, the subjects were exposed to a +7G_z ROR (Rapid Onset Rate = 1.0 G/second) acceleration for 60 seconds. Immediately after the ROR, the subjects were reexposed

to the GOR and taken to their tolerance limit. RESULTS. The subjects relaxed tolerance on the first GOR (Pre-HSG) was 5.4 $+G_z$ ± .07 (mean ± S.D.) and their second GOR tolerance (post-HSG) was 4.5 ± 0.6. Statistical significance via Student's T test (2 tailed) was p=.065, but 5 of the6 subjects had a reduction in post-HSG tolerance. Electrocardiogram and heart rate evaluation provided an indicator of the cardiovascular response. CONCLUSIONS. This study suggests that relaxed $+G_z$ tolerance is lowered following a high G exposure. Such a post-HSG reduction in relaxed tolerance would place a greater burden 0n the pilot's G protective systems, thereby limiting one's ability to fully utilize the capability of the aircraft."

Shaffstall RM, Morgan TR. A review of ATAGS research and development in the Armstrong Laboratory. 34th Annual SAFE Symposium Proceedings. 1996;357-63.

Abstract: "The full coverage anti-G suit concept used in the ATAGS (Advanced Technology Anti-G Suit) is not new. In fact, research to evaluate full coverage anti-G suits preceded the development of the "cut away" five-bladder anti-G suit that is used today. While early research showed that the full coverage concept held promise, the simpler and less expensive five-bladder suits provided good acceleration protection and met known G-protection requirements. Interest in the full coverage anti-G suit concept was rekindled in the Armstrong Laboratory in the 1970s. In retrospect, the Armstrong Laboratory's anti-G suit research and development efforts were conducted in two phases. The first phase involving concept development and validation extended from 1974 to 1988. This phase included evaluations of full bladder suits, capstan suits, mini-capstan suits, reticulated foam filled suits and a number of different versions of the ATAGS. The second phase of the ATAGS maturation process involved modification of the suit to improve operational utility and was characterized by flight evaluations and laboratory validation of modifications. This phase of development resulted in a change in suit design from a full coverage concept to a uniform circumferential pressure concept. Centrifuge and flight tests conducted during the second phase of development continued to show that the ATAGS provided improved G-protection."

Shaffstall RM, Perez R, Self DA. High G-onset and inflation time evaluation of the Advanced Technology Anti-G Suit (ATAGS). 32nd Annual SAFE Symposium Proceedings. 1994:24-7.

Abstract: "Centrifuge Evaluations have repeatedly demonstrated that full coverage anti-G suits, e.g., Advanced Technology Anti-G Suit (ATAGS),will significantly improve acceleration tolerance as measured by endurance type acceleration profiles. Flight evaluations in fighter aircraft have also demonstrated the G-protection value of the ATAGS; however, the full coverage anti-G suit requires a larger volume bladder which increases suit inflation time and may affect acceleration tolerance to high-G onset accelerations. The purpose of the studies documented in this Technical Report were to evaluate the inflation characteristics and the G-protection capability of the ATAGS relative to the CSU-13B/P anti-G suit. Engineering testing and manned centrifuge studies were conducted to evaluate the ATAGS volumes, inflation times and $+G_z$ tolerances. Ten experienced male centrifuge subjects were exposed to high-G onset (6G/s) accelerations at $+7G_z$,$+8G_z$ and $+9G_z$. While the ATAGS was found to inflate slower than the CSU-13B/P anti-G suit, both subjective results (questionnaire data) and objective results (heart rates) indicated that the ATAGS provided good protection during high-G onset accelerations."

Travis TW, Morgan TR, Shaffstall RM, Yamrose DW. COMBAT EDGE/ ATAGS effect of fighter pilot G tolerance during centrifuge demonstration. Aviat. Space and Environ. Med. 1995;66:478.

Abstract: "INTRODUCTION. COMBAT EDGE the USAF positive pressure breathing for G (PBG) is not widely fielded in the F-16 and will soon be fielded in the F-15. The next step toward improving anti-G protection is the addition of a full-coverage lower body anti-G garment (Advanced Technology Anti-G Suit or ATAGS) which increases the effectiveness of PBG. A demonstration of this combined anti-G protection was performed on the centrifuge with volunteer fighter pilots. METHODS. Eight fighter pilots (4 F-15 and 4 F-16) were exposed to three centrifuge profiles while wearing the standard five-bladder CSU-13B/P anti-G garment in their appropriate seat configurations. On a subsequent day, they were exposed to the same three profiles while wearing COMBAT EDGE and ATAGS. Onset of straining (resting tolerance) during a gradual onset run (GOR, 0.1 G/sec) , maximum G attained on the GOR with strain, and simulated air combat maneuvering (SACM) tolerance were compared. RESULTS. There was a significant increase ($p < .05$) in resting G-tolerance on the GOR's wearing COMBAT EDGE and ATAGS. All eight pilots attained 9 G's on the GOR while wearing COMBAT EDGE/ATAGS compared to only one wearing the CSU-13B/P. There was a significant increase in SACM tolerance with the COMBAT EDGE/ATAGS combination, with seven of eight completing the maximum 51 sec. exposure. Subjective comments regarding protection were overwhelmingly positive. Negative comments pertained mainly to donning and encumbrance. CONCLUSIONS. The COMBAT EDGE/ATAGS combination provides significantly increased anti-G protection and will support improved safety and performance in the high sustained G environment."

26.13 Computer Systems and Application Software

The contractor shall configure and maintain PC- and Macintosh-based workstations used for data acquisition, instrumentation, and equipment control and provide computer hardware and application software support. (DIN: A017)

The contractor shall provide support for data collection, real-time display, data reduction, and data analysis for in-house research and provide training and support of computer generated output for presentations and publications. (DIN: A017)

The contractor shall configure and maintain network services and cross platform compatibility as well as evaluate new software products and computer hardware technologies. (DIN: A017)

Accomplishments

The work accomplished under this Task Order involved the maintenance and upgrade of Division Macintosh computers, their integration into the Division Local Area Network (LAN) and support for data reduction, graphics application and training. The KLSI Technician assisted in the fabrication and setup of the Division LAN and Servers particularly in the integration of the World Wide Web (WWW) onto the system by preparing Hypertext Mark-up Language (HTML) links

and WWW pages. Presentation materials were prepared for Division personnel for a number of Symposia and technical meetings. Training of Division personnel in the use of scanning techniques and software as well as graphics packages was accomplished throughout the period of this Task Order. The Engineering Support Office was also supported in the configuration and maintenance of NT and Windows based systems. Evaluation of specific items of computer hardware, peripherals and software was accomplished. Equipment and materials required for LAN integration were procured, configured and installed. Examples of significant specific accomplishments include:

a. Full implementation of a Macintosh based server.

b. Set up and provided Macintosh applications on the NT Server.

c. Examples of equipment evaluation include: Apple Digital Camera, Kodak Digital Camera, Kodak Digital Film Recorder, Polaroid Digital Slide Scanner, Epson Color Scanner, Proxima Digital Video Projector, Hewlett Packard Color Printer.

d. Development of WWW Division Home Pages.

e. Conversion of the Aeromedical Research Status Guide to HTML.

26.14 High Performance Molecular Sieve Oxygen Generation System

The contractor shall aid in the development and provide expertise necessary for the design of a prototype of HP-MSOGS which shall meet FDA Certification requirements. The contractor shall design a micro-controller which will be used to control and monitor the system operation when producing oxygen. The contractor shall coordinate with Creare, Inc. during the design and fabrication of the HP-MSOGS. The HP-MSOGS shall be designed to the following specifications: (DIN: A007, A008, A009, A010, A011, A016, A017, A018)

The contractor shall write a system/segment specification according to MIL-STD-490A Section 3 paragraphs 3.1.11, 3.1.3.1, 3.2, Section 4 and Appendix I (DIN: A016)

The contractor shall provide materials and components to fabricate a prototype unit. The HP-MSOGS shall be designed for convenient integration into the prototype AHOS. (DIN: A019, A020, A021)

The contractor shall prepare a comprehensive test plan and test procedures for the HP-MSOGS. Also, the test plan shall include FDA requirements. The contractor shall also conduct laboratory testing to verify the requirements of HP-MSOGS, as specified in 3.a, and provide technical reports documenting results and performance. (DIN: A019, A020, A021)

The contractor shall provide general technical assistance or consultative support to other oxygen generating research and development (R&D) efforts.

Accomplishments

To minimize the technical risk in developing a 30 liter/minute HP-MSOGS, scaled laboratory prototype devices were designed, constructed and tested. This course of action minimized fabrication costs associated with finding the most promising design. Variables modified, to improve the performance, are the bed design (as it directs the air stream through the molecular sieve), cycle time, purge flow, and pressurization procedures. Three small bed configurations were evaluated. Configurations based on a concentric/annular concept, a conical concept and a multi pass/reverse baffle concept were considered. Additionally, to serve as a benchmark for comparison purposes, a larger device containing 65 pounds of molecular sieve was constructed to determine its performance as it relates to large scale, in line, molecular sieve bed geometry. Information gained would be compiled to develop the design for the 30 liter/minute HP-MSOGS.

Designed, fabricated and tested were: a 5 Liter "Annular" HP-MSOGS, a 5 Liter "Conical" HP-MSOGS, a 5 Liter "Reverse Baffle" HP-MSOGS and a "true" size device denoted as the 65 MS HP-MSOGS. The low flow, 5 Liter, design that performed the best was the Reverse Baffle. This design increases the amount of zeolite molecular sieve coming into contact with the air stream, causing an increase in the amount of nitrogen removal. Data collected show that 99% oxygen can be produced at 9.5 Standard Liters Per Minute with the inlet air pressure being 80 psig. This concept was then scaled up to create the 30 liter/minute HP-MSOGS designs: one with two canisters with a square outer geometry and cylindrical, internal zeolite reverse baffles; the other with six canisters, each with a cylindrical geometry and internal zeolite reverse baffles.

A series of test matrices, to determine optimum operational conditions (supply pressures and product flows as a function of cycle times and purge orifice sizes) were conducted on the two, 30 liter/minute HP-MSOGS systems. The most favorable results were achieved with a portion of the bed configuration for the six bed unit. In order to expedite testing, the response/performance of bed pairs were studied. This approach made available the possibility for a faster progression through the test matrices. During this phase of testing, the data revealed a progressive deterioration in the oxygen product concentration. A rationale for this phenomena is currently being sought and a solution is pending. In an effort to explain this phenomena, the small scale 5 Liter "Reverse Baffle unit is being reconstructed and will be operated at the conditions that produced it's earlier, recorded favorable results.

A 1/8th scale model was created to illustrate component layout and the interfacing of the HP-MSOGS with the Cryogenic subsystem. Also, a safety assessment report and test plan was developed and submitted for review. The intent of the report was to identify any hazards associated with the operation of the HP-MSOGS and the cryogenics system comprising the Advanced Hybrid Oxygen System - Medical (AHOS-M) device. The project did not progress to the point of designing a micro-controller to control and monitor the system operation. All algorithims were implemented from a personal computer based platform.

The process for obtaining the approval from the Food and Drug Administration (FDA) to market the Advance Hybrid Oxygen System - Medical (AHOS-M) was initiated. The review of available literature regarding the FDA approval process revealed that the simplest and less expensive route

is to be able to claim substantial equivalence to an already existing FDA approved device on the market. The services from the firm of Hogan & Hartson was contracted to assist in the FDA approval process. They provided experience in this area and acted as a liaison to the FDA on behalf of the Air Force. The Research Engineer from KLSI worked in conjunction with an Air Force Officer to provide the explanation of how the AHOS-M device operated and how it could be claimed to be substantial equivalent. The last correspondence with the firm of Hogan & Hartson relates that the FDA is to give a ruling on whether or not the claim for substantial equivalence is valid.

The availability of a sufficient supply of compressed air and the bulk of conventional compressors are two of the challenges when using pressure swing adsorption technology. Therefore, a way of merging a pressure swing adsorption system directly with a compact compressed air source warranted further investigation and research to explore the viability of the system configuration as a solution to the present challenges.

An experimental unit was constructed by connecting two OBOGS beds directly to a dual acting compressing piston. The piston drew in air at atmospheric pressure and then compressed the air into one of the OBOGS beds. Because the piston was dual acting it compressed on both the down and return stroke. While one side of the piston was pressurizing bed A, the other side was drawing in fresh air as bed B exhausted. The piston was driven by a linear actuator. The actuator was programmed to run at a wide variety of velocity and acceleration profiles. The speed of the actuator determined the cycle time and maximum pressure obtained. Two different sieve bed volumes (35 in^3 and 14 in^3) were tested with the unit to find the best cylinder to bed volume ratio.

The two sets of beds were optimized using the air cylinder as the compressed air source and then using a conventional air source. The best results based on the highest recovery rates and highest product flow of oxygen above 90% are listed in the following two tables.

Highest Recovery	Air Cylinder 35 in^3	Conventional 35 in^3	Air Cylinder 14 in^3	Conventional 14 in^3
Percent Recovery (%)	14.7	22.4	19.3	20.5
Product Flow (SLPM)	0.754	2.087	0.5	0.491
Oxygen Concentration (%)	90.98	91.454	90.55	90.46
Production Capacity (mole m^3_oxygen/m^3_bed/hr)	35	97	58	56

Highest Product Flow	Air Cylinder 35 in^3	Conventional 35 in^3	Air Cylinder 14 in^3	Conventional 14 in^3
Percent Recovery (%)	14.7	21.8	14.3	11.4
Product Flow (SLPM)	0.754	2.006	0.6	0.491

Oxygen Concentration (%)	90.98	92.067	91.08	93.59
Production Capacity (mole m^3 oxygen/m^3 bed/hr)	35	94	70	59

The highest purity (% Oxygen concentration) achieved using the Air Cylinder and Conventional approaches were 91.08% and 93.59%, respectively. As expected, these results diminished as the product flow rates increased. For the experimental maximum product flow rate of 2.087 slpm, the product purity was 91.454% using the conventional approach. In comparison with the Air Cylinder approach, the experimental maximum product flow rate of 0.754 slpm yielded a product purity of 90.98%.

As can be seen in the data, the larger volume bed did not perform as well as the smaller bed when supplied by the air cylinder. The air cylinder was not large enough to supply compressed air to the large bed fast enough at a sufficiently high pressure. The smaller bed was better matched to the air cylinder and yielded a higher production capacity than a comparable, conventionally operated arrangement for a PSA device. A smaller bed volume could possibly yield an even higher production capacity. In order for this technology to become usable for field use a more reliable slow speed piston ring or faster adsorbing sieve would have to be developed.

In an effort to make HP-MSOGS more efficient and therefore lighter and smaller, better ways of maximizing the adsorption capability of the carbon and zeolite sieves needs to be developed. Much research has been done to map the characteristics of zeolite sieve, but little has been done to understand the characteristics of carbon sieve.

A test was devised to study the effects of sieve pellet size and carbon bed diameter on HP-MSOGS performance. Three pairs of beds were constructed. All three pairs had the same volume, but three different diameters were used. Each of the three bed pairs was tested with three different sieve sizes. All nine configurations were fed from the same pair of zeolite beds.

The following results are the best runs from each configuration.

Bed Geometry	Sieve Size	Cycle Time (sec)	Oxygen (%)	Nitrogen (%)	Argon (%)	Inlet Pressure (psia)
Fat	6x12	8	91.40	7.462	1.073	40.1
Middle	6x12	7	91.52	7.427	0.981	44.9
Thin	6x12	7	89.93	8.588	1.419	45.4
Fat	10x40	12	95.70	3.48	0.754	35.4
Middle	10x40	11	98.56	1.097	0.287	40.0
Thin	10x40	12	98.84	0.866	0.239	40.0
Fat	20x60	6	95.80	3.629	0.51	49.4
Middle	20x60	6	97.34	2.351	0.247	54.2
Thin	20x60	5	97.53	2.228	0.182	64.2

The product flow for each run was 0.5 liters. The best overall run was accomplished using the thin bed with the 10x40 mesh sieve. It was found that the optimum cycle time is closely linked to the sieve size, but not to the bed geometry. The thinner bed geometry does cause a definite reduction in nitrogen and argon concentrations. It was also noted that a change in the carbon bed has a direct effect on the zeolite bed.

Because the performance of the carbon and zeolite beds is so strongly linked, a more comprehensive study, including changes in the zeolite bed, would need to be done to gain further understanding of the HP-MSOGS technology.

Research reports (DIN A005, DIN A009, DIN A010, and/or DIN A016) from this effort include:

Miller GW, Fenner JE. A "Smart" Molecular Sieve Oxygen Concentrator with Continuous Cycle Time Adjustment. 33rd Annual SAFE Symposium Proceedings 1995;357-368 and AL/CF-TP-1996-0002. 1996;1-19 and SAFE J. 1996;26:25-33.

Abstract: "A "smart" molecular sieve oxygen concentrator (MSOC) is controlled by a set of computer algorithms. The "smart" system automatically adjusts concentrator operating parameters to accurately control product oxygen concentration while minimizing bleed air consumption. The purpose of this effort was to determine if concentrator performance could be controlled by computer algorithms which continuously adjust concentrator cycle time. A two-bed laboratory molecular sieve oxygen concentrator was constructed and instrumented. The concentrator was operated at ground level and ambient temperature. Computer algorithms or decision processes were developed which allowed the software to control concentrator cycle time. Step changes in product flow from 5 to 40 standard liters/minute were induced by a flow controller. A signal representing the product oxygen concentration was produced by a medical gas analyzer and inputted into the computer algorithms. Using continuous cycle time adjustment over a range of 14 to 36 seconds, the "smart" concentrator maintained the product oxygen concentration within 2.5% of a desired oxygen concentration. The smallest incremental change in cycle time was 0.5 seconds. The highest observed overshoot in oxygen concentration which occurred during the step changes in product flow was about 12%. Inlet air consumption was reduced by approximately 40% when compared to operation at a constant cycle time. "Smart" MSOC techniques, such as continuous cycle time adjustment, can significantly improve our ability to control oxygen concentrator performance. An added benefit will be reduced bleed air consumption which results in increased aircraft thrust and fuel economy."

Miller GW, Fenner JE. Engineering Qualification Testing of the F-15E Molecular Sieve Oxygen Generating System. 34th Annual SAFE Symposium Proceedings 1996:364-373.

Abstract: "The purpose of the effort was to ensure the F-15E MSOGS delivered oxygen concentrations which met the system performance specifications during all phases of the mission profile. Functional tests of the integral backup oxygen system were also conducted. The MSOGS was tested in a two compartment altitude chamber. One compartment simulated cabin altitude and the other aircraft altitude. MSOGS inlet air temperatures used in the study were 24 and 55 °C. Inlet air pressures were 30 and 55 psig. Unmanned testing was accomplished at

steady-state product flows up to 100 ambient liters/minute (ALPM). In general, the MSOGS produced oxygen concentrations above the performance specification. However, some test conditions at the highest product flow rates and the lowest expected operating pressure (30 psig) produced oxygen concentrations below the performance specification. These conditions resulted in automatic activation of the backup oxygen system. Also, tests showed the backup oxygen system could store sufficient oxygen to supply the aircrew with oxygen for approximately 10 minutes at ground level. Based on performance testing at the predicted operating conditions, the F-15E MSOGS passed engineering qualification testing up to an aircraft altitude of 50,000 feet. At high breathing flow rates the backup oxygen system may momentarily activate."

Miller GW, Fenner JE. Evolution and Operational Use of Molecular Sieve Oxygen Concentrator Systems. AL/CF-SR-1995-0021. 1995:75-106.

Abstract: "The purpose of this paper is to review the development of molecular sieve oxygen concentrator systems. Emphasis will be placed on U.S. Air Force systems. Oxygen concentrator performance, operational use, and backup oxygen system capacity will be discussed. Further, potential future technologies which may be applied in aircraft oxygen systems will be mentioned. Presently, molecular sieve oxygen concentrator (MSOC) technology is routinely applied on military aircraft for the generation of an oxygen enriched breathing gas to prevent hypoxia. MSOCs use a technique known as pressure swing adsorption (PSA) to separate oxygen from engine bleed air. This technique has grown in popularity in recent years because of its simplicity, reduced energy consumption, and low operating costs when compared to conventional liquid oxygen systems. Use of MSOC technology on military aircraft eliminates the liquid oxygen logistical requirements and safety issues, decreases aircraft turn-around time, allows more options for aircraft basing, extends mission time if limited by the quantity of liquid oxygen, and significantly lowers operational costs. Although many types of oxygen generating systems, such as permeable membrane, electrochemical, organic chelate, and ceramic have been investigated for aircraft use, only MSOC technology has been installed on production aircraft."

Miller GW, Russell RL, Holden RD, Wilkins AG, Stork RL, Brown CE. Engineering Qualification and Human Performance Testing of the F-15E Molecular Sieve Oxygen Generating System (MSOGS). AL/CF-TR- 1997;1-136.

Abstract: "The F-15E MSOGS demonstrated that it will adequately support a two man crew wearing standard USAF flight equipment up to an altitude of 50,000 feet above sea level. Breathing characteristics did not meet the ASCC standard for aircrew breathing systems, but are no worse than the current operational system which uses the CRU-73/A regulator with liquid oxygen. Emergency operation of the system following a rapid decompression or a situation requiring undiluted MSOGS product gas and/or safety pressure was verified. The MSOGS performed well with COMBAT EDGE equipment. The regulator provided pressure breathing for G (PBG) within safe physiological limits. Breathing characteristics with COMBAT EDGE fall either within or near the ASCC standard."

26.15 Unfunded Task

26.16 Technical Support for the ATAGS

The contractor shall assist in the fabrication of ATAGS to be used in verification/validation testing. The contractor shall write test plans and procedures to verify/validate the performance of ATAGS. Assist with the testing of ATAGS in accordance with the approved test plans/procedures. Prepare test reports which document the test results of the ATAGS testing. (DIN A019, A020, A021)

Accomplishments

KLSI assigned a Life Support Equipment Engineer/Specialist to assist the Lead Acceleration Scientist and the Lead Engineer. The task order was modified to include the development of additional suit sizes and further testing. To support the modified task order, KLS assigned a Lead Acceleration Scientist and a Soft-Goods Fabrication Specialist to the effort.

Specific accomplishments.

1. Validated the ATAGS design, patterns, drawings and product function specification by fabricating 10 ATAGS (Sizes 2, 4, 5, 6, and 8). Provided the suits to the Human Systems Center, Life Support Systems Program Office (HSC/YAS). Using the David Clark Co. patterns, drawings and product function specification as an initial design, KLS supported the fabrication of 10 ATAGS (2 ea. in sizes 2, 4, 5, 6 and 8). The following changes to the David Clark design were identified during the development process and the design of the suit was modified accordingly. Following leak testing at 10.5 psi and proof pressure testing at 13.7 psi, the 10 ATAGS were provided to HSC/YAS for qualification testing. Changes to the David Clark Co. ATAGS Design: Eliminated the pressure sock and removed the pressure sock connections. (pressure sock deleted from design); replaced the two layer Nomex under zipper flap with 3" Nomex tape. (improve/simplify design); added reinforcing tape to the outer restraint seams that bear the greatest stress (eliminate windowing); replaced the light-weight waist donning hook with a snap. (eliminate FOD); and replaced the lower leg restraint snap with a zipper retention tab and snap. (prevent inadvertent zipper opening). These changes were incorporated into the ATAGS drawings, patterns and product fabrication specification. The drawings and patterns were digitized in AutoCAD format. A total of 34 sheets of drawings and patterns were developed. The entire drawing and product function specification package was provided to HSC/YAS for review. Changes suggested by HSC/YAS were incorporated into the data package and the finalized documents (10 x3.25" computer disks) were provided to HSC/YAS via AL/CFT. Ten baseline configuration ATAGS (2 ea. in sizes 2, 4, 5, 6 and 8) were delivered to HSC/YAS. Copies of all patterns, drawings, and the product function specification were delivered to AL/CFT via electronic media (AL/CFT Y:\Common\ATAGS and 10 x 3.5" computer disks).

2. KLS initiated a qualification test and evaluation program to meet the requirements identified in the Critical Item Development Specification (CIDS) HSCATAGS -001, dated 18 July 1996. Prior to the completion of the test program, newer versions of the CIDS (7 Nov. 96 and 17

DEC 96) were released. While some testing was conducted to meet the test requirements specified in older versions of the CIDS, the 17 Dec. 96 document was used to establish requirements for the majority of the tests and analysis. Interim test reports were provided on 19 July 96, 24 Sep 96 and 19 Dec 96. Per the request of HSC/YAS, a final report incorporating all submissions was provided. Delivered ATAGS Qualification Test Report, Final, Dtd. 20 Oct 1997. Accomplishments under the modified tasking included: Provided 2 ea. ATAGS (4 suits total) in sizes 1 and 9. Size 1 and size 9 patterns and suits were not provided under the KLS subcontract to the David Clark Co. (Task Order 004); however, pre-David Clark patterns were available for comparison. To fabricate the size 1 baseline configuration suit, KLS graded down a baseline size 2 suit to meet the length requirements of the size 1. A size comparison was between the baseline size 1 and the pre-David Clark size 1 was conducted to ensure accurate segment lengths and circumferences. A similar process was followed to develop the size 9 suit. A baseline size 8 suit was graded up to meet the size 9 length requirements and the new baseline size 9 was compared with the pre-David Clark size 9. The fabrication process for the suits was validated by fabricating 2 suits in each size. The patterns for the size 1 and size 9 suits were finalized and added to the drawing packages. Submission of the patterns for the size 1 and size 9 suits to HSC/YAS was included in the products provided under Objective 1. Delivered four baseline configuration ATAGS (2 ea. sizes 1 and 9) including the patterns. The patterns were combined with Objective 1 deliverables and provided to HSC/YAS. Patterns available at Y:\Common\ATAGS.

3. KLS developed an improved secondary restraint system and improved zippers. During the ATAGS development process the need for a secondary restraint system was recognized. The purpose of the secondary restraint was to aid in suit donning and to restrain the suit (prevent ballooning of the leg bladders) in the event of zipper failure. The ATAGS design provided by the David Clark Co. under task order 004 included a secondary restraint system that used 0.75" Fastex plastic side release buckles. During the task order 004 development process, these buckles were found to have a breaking strength of 154 lbs. This breaking strength was thought to exceed the stress that could be applied in the event of a zipper failure. In addition, in the event of zipper failure, the pilot would unload the aircraft (decrease the $+G_z$ level) very quickly and it was assumed that the suit pressure would not reach high pressures. To support this theory, a navy test pilot experienced an inadvertent zipper failure in flight and the plastic buckles held. Further testing in the laboratory revealed that in most cases of zipper failure, the plastic buckles would break and the suit could balloon. Thus, the development or identification of a stronger buckle was needed.

The initial effort to identify a stronger buckle/secondary restraint system was to conduct a search for commercially available buckles or hooks that would have adequate strength to restrain the suit. A number of buckles and hooks were procured and evaluated. A snap ring (mountain climbers carabinner) and loop combination was installed on a older ATAGS for don/doff test purposes. The concept was discarded when It was found that the snap ring would damage the loop tape during hooking and unhooking. Other types of snaps were evaluated and discarded as being too bulky. A flat stainless steel hook, designated as the "a" hook, and loop combination was fabricated and found to be successful in secondary restraint strength tests conducted on suit # 93-8 (see attached. ATAGS Qualification Test Final Report). The "a" hook and loop was installed

on all baseline ATAGS. However, the "a" hook and loop combination was found to be minimally acceptable during aircrew don/doff trials conducted by HSC/YAS. Subsequent to the installation of the "a" hooks on the baseline ATAGS, a receiver (insert) was developed to improve the suit's don/doff performance. A size 9 ATAGS (suit # 98-9) was modified with the "a" hook and insert. The "a" hook and insert successfully passed the secondary restraint strength test, (ATAGS Qualification Test Final Report).

In addition to the improvements made to the secondary restraint system, the ATAGS zipper system was improved by modifying the suit design to allow leg zipper replacement. The ATAGS was modified by integrating a length of Nomex tape into the restraint layer of the suit and sewing the leg zippers onto the Nomex tape. This modification allows the life support equipment specialist to remove and replace the leg zippers without opening sewed seams in the suit restraint layer. This modification may increase the operational life of the suit allowing zippers to be replaced several times depending on the overall condition of the suit. Secondary Restraint System design and drawings were delivered as a part of the package provided to under Objective 1. KLS modified 14 ATAGS to "a" hook and loop design secondary restraint system including replaceable zippers for all suits. KLS modified and tested suit #98-9 to "a" hook and insert design. The test report was included in the ATAGS Qualification Test Report.

26.17 Technical Support for the AAOM - Terminated at the Convenience of the Government

26.18 Computer Assisted Design Engineering Support

The contractor shall use a sonic 3-D digitizing machine to obtain anthropometric data and impute this data to 3-D CAD/CAM software; perform 3-D CAD/CAM design and modification of aircrew oxygen masks using computer modeling software package including the documentation of the AAOM design (DIN A018); and assist in the fabrication of mask prototypes by enabling computer models to be fabricated using a fused deposition modeler (FDM) machine.

In addition, the contractor shall purchase a digital data recording system, a medical monitor station, an a character inserter video display to collect AAOM data under dynamic test conditions.

The following work shall require the efforts of outside agencies: Fabricate the facepiece of the MBU-20/P oxygen mask with new technologies incorporated into the seal area of the mask. These seal technologies are based upon conformable materials which will cause the surface or contact area of the seal to increase as mask pressure is applied to the face. A laboratory demonstrator design is to be built which shall incorporate on a form of material such as an ergometric foam or gel. The facepieces shall be constructed to the proper dimensions to fit into the Small Narrow and Medium Narrow sizes of MBU-20/P mask hard-shells. Two copies of each size are to be provided for a total of four masks. Seal dimensions shall correspond approximately to the dimensions of the existing reflective seal of the MBU-20/P mask. Design and build a new size of the MBU-20/P oxygen mask as specified by Government provided data. The mask facepiece and hard-shell are the only items which vary with size and are therefore the only items of consideration in this task. Each item shall be constructed of similar material as the existing

Gentex facepiece and hardshell and resemble the existing MBU-20/P design and material. Four copies of the new mask size shall be produced to permit efficient fit testing of the mask in the field. Provide the necessary equipment, software, and supplies for the design, modification, and fabrication of mask brassboards and mask subsystems.

Accomplishments

KLSI provided engineering support to design AAOM using advanced 3-D computer Aided Design and Computer Aided Modeling (CAD/CAM) equipment, and supported the fabrication of the masks using both advanced techniques (Fusion Deposition Modeling) and conventional techniques. The modified task order included need for outside agencies to develop and fabricate laboratory demonstrator oxygen mask inserts, conformal seal oxygen masks, a new size oxygen mask and to acquire equipment needed to conduct oxygen mask testing. KLS assigned an Electrical Engineer (full time) to conduct the in-house mask development and a Life Support Engineer/Specialist (part time) to assist in the outside agency effort. KLS subcontracted for the following efforts:

a. To build laboratory demonstrator face-pieces and hard-shells for the MBU-20/P oxygen mask with the seal constructed of a conformal material (such as gel or ergometric foam).

b. To build laboratory demonstrator face-pieces and hard-shells for the MBU-20/P oxygen mask to a new size specification.

c. To acquire the equipment necessary to capture AAOM data during dynamic testing.

The KLS Engineer supported the development of an anthropometric data acquisitions system to acquire and digitize 3-D anthropometric facial data. By using a microsphere filled elastic vacuum bag to establish a negative of the face, the system eliminates most of the labor intensive and potentially inaccurate manual aspects of facial anthropometry measurement. In addition to improved accuracy and less labor, the system accommodates for the compressible nature of facial tissue and provides a face form that is more realistic relevant to the actual fit of an oxygen mask. A patent application was submitted for the concept.

The KLS Engineer also supported the establishment of efficient automated systems to incorporate digitized facial anthropometry data into CAD/CAM programs and rapid prototyping systems. These systems were used to fabricate mask components and molds. In addition, the systems were used to fabricate custom fit MBU-12/P and MBU-20/P oxygen masks starting with the vacuum bag anthropometry system to establish the individual face form and utilizing automated techniques to fabricate the mask hard shells and the injection molds used to form the mask soft shells. In addition, KLS provided 40 MBU-20/P oxygen mask inserts via a purchase agreement with the Gentex Corp., Rancho Cucuamonga, CA.

KLS delivered:

a. 2 ea. of two different conformal face seal MBU-20/P oxygen mask soft-shells via a purchase agreement with Gentex.

b. An extra-small (new size) MBU-20/P oxygen mask soft shell and hard shell via a purchase agreement with Gentex.

c. Data collection and recording equipment for use in static and dynamic AAOM testing. Equipment included: a Racal recorder and associated equipment, an Emcor Console, a Panasonic monitor, a high resolution monitor, and a video annotator and associated software.

26.19 Computer Systems and Application Software Support

The contractor shall provide hardware and software support for both PC- and Macintosh-based computer systems. This includes: installing, upgrading, troubleshooting, repairing, configuring, and maintaining computer hardware, software, and peripherals used for office automation, information generation, data acquisition, and equipment control. (DIN: A017)

The contractor shall provide personnel training of office automation, information generation, and computer generated output for presentations and publications and evaluate new software products and new computer hardware technologies. (DIN: A017)

The contractor shall configure and maintain network services within a heterogeneous computer environment and provide software support for division WWW pages, database management, data collection, real-time display, data reduction, and data analysis for in-house research (DIN: A017)

Accomplishments

Work accomplished under this Task Order was to a great degree the continuation and expansion of work begun under Task Order 13. Day to day work accomplished included: the acquisition of materials, equipment and computer systems, preventative maintenance, troubleshooting, repair and upgrade of Macintosh computers and peripherals, preparation of graphics for Symposia and technical meetings, training of Division personnel on Macintosh and PC applications software, and configuration of Macintosh systems for the Division LAN and e-mail systems. Specific examples of the work accomplished under Task Order 19 include:

a. Design and creation of a standardized template and installation disk for all Macintosh computers on the Division LAN. This work was expanded to include configuring the Macintosh operating system on the LAN and incorporation into the Novell GroupWise e-mail system.

b. Digital photography or scanning support was provided to produce digital images of all Division personnel for individual identification plates.

c. Provided audio-visual support for the Armstrong Laboratory wide "Acquisition Air Force Down Day" at Randolph AFB.

d. A Division wide inventory of all Macintosh computers, associated Operating System versions, and peripherals was accomplished. Recommendations for retirement or replacement of out dated equipment and peripherals were made.

e. Planning and recommendations for moving Macintosh service to the NT, Novell system.

f. Preparation and maintenance of HTML links and WWW pages.

g. Assisted in planning the upgrade to the Win 95 Operating System for the Division.

26.20 High Altitude Protection Research

The contractor shall develop and conduct human subject research protocols designed to investigate the impact of altitude on the development of gas bubbles in the body and the incidence of DCS; prepare scientific reports for publications to document experimental methods, test results, and conclusions. (DIN A016). The contractor shall assist in the development of a statistical based computer model for the prediction of DCS risk associated with any altitude exposure (DIN A017). The contractor shall develop and conduct human subject research protocols to investigate the physiological effects of hypoxia and positive pressure breathing; prepare scientific reports for publications to document experimental methods, test results, and conclusions (DIN A016). The contractor shall provide supplies and equipment necessary for testing as follows:

Mass Spectrometer (Marquee) - Model M-100
Intertechnique Breathing Hoods - Model #3422
PBM PC 486 or equivalent

The contractor shall provide a state of the art echo imaging system for use during altitude experiments and provide an Echoimaging Technician whose duties shall include but not be limited to: 1) operating a state of the art ultrasound imaging system; 2) performing cardiac and vascular imaging; 3) providing general support for human subjects before, during and after experiments; and 4) recording and entering research data.

Accomplishments

AFRL Hypobaric DCS Research Database

Data from 1704 subject-exposures were imported from the VAX-based database system to Microsoft Access 7.0 format. All data were subsequently converted from coded data to text. Data from 198 subject-exposures were entered directly into the new database. Fifteen (15) tables,

149 macros, 73 forms, 78 queries, and 45 reports were written to provide desk-top access to continually updated reports. These include monthly progress reports used for KLSI, military, and Government reports, annual progress reports, data entry reports, multiple result reports for each study in the database, and specific data reports as requested. Data entry of 48 subject-exposures was checked and verified. (DIN A016 and DIN A017)

Research reports (DIN A005, DIN A009, DIN A010, and/or DIN A016) from this effort include:

Krause KM, Webb JT, Pilmanis AA. The effect of menstruation day on decompression sickness (DCS). (Abstract) Aviat. Space Environ. Med. 1998;69:[In Press].

Abstract: "INTRODUCTION. The role of women in Air Force operations has expanded greatly in recent years. As part of an on-going effort to resolve the role of gender in DCS susceptibility, the effect of menstruation day on DCS incidence was explored. One report has indicated that there exists an inverse linear relationship between the start of the last menstrual period and the incidence of DCS. The report was limited to a retrospective study of female patients who received hyperbaric treatment for DCS symptoms, which occurred as a result of a variety of altitude exposure scenarios. The purpose of this prospective study was to determine if a relationship exists between menstrual day and DCS incidence. METHODS. Data were analyzed from 152 altitude chamber subject-exposures. Menstrual day, preoxygenation duration, exposure altitude, activity at altitude, DCS outcome, maximum venous gas emboli (VGE) grade, and medications, including oral contraceptives, were recorded for each exposure. The altitudes of the exposure were 21,200 ft (n=10), 22,500 ft (n=23), 25,000 ft (n=33), 30,000 ft (n=46), and 35,000 ft (n=40). RESULTS. 62 cases of DCS were reported (41% of female subjects exposed to altitude). Multiple logistic regression analysis showed that an overall significant correlation exists between menstrual day and DCS incidence (p=0.0029). The probability of DCS is highest at menstrual day 2 and decreases as menstrual day increases. For each altitude individually, a significant correlation exists between menstrual day and DCS incidence for 30,000 ft (p=0.0028). The correlations were not significant for the other altitudes tested. CONCLUSIONS. Menstrual day and DCS incidence are correlated. Operationally, this correlation would appear to play a role in exposures with moderate DCS risk. At low altitudes, where DCS risk is low, menstrual day is not an important predictor of DCS risk. In a similar manner, at high altitudes, where DCS risk is high, menstrual day is again not an important predictor of DCS risk."

Pilmanis AA, Krause KM, Webb JT. Optimizing the physiological concepts for future extravehicular (EVA) operations. Reusable Launch Vehicle Human in Space Workshop Proceedings. 1997 [In Press].

Abstract: "Two decades of EVA experience in Shuttle operations, advancements in physiological research, and the Reusable Launch Vehicle (RLV) development provide a timely "window of opportunity" for reevaluation of EVA equipment and operations. Future space objectives including permanent occupation of the International Space Station, commercial and military RLV development, and missions to both the moon and Mars require broad EVA capabilities. Human exposure to reduced atmospheric pressure poses several potentially serious physiological problems including hypoxia, ebullism, and decompression sickness (DCS). Critical

issues to be addressed for reaching these objectives include the definition of optimum pressures for EVA suits, acceptable DCS risk limits, new preoxygenation schedules, reassessment of fire protection, and reevaluation of breathing gas mixtures. The greatly expanded list of future mission scenarios dictates the development of a variety of EVA countermeasures and capabilities versus the limited nature of those in the past. Incorporation of concepts such as exercise-enhanced preoxygenation, inert gas switching, hypoxia acclimatization, computer-controlled atmospheres to limit DCS risk, and variable rates and staging of decompression will provide the expanded capability. Some of these evolving concepts are discussed in this paper."

Model Validation Study

The objective of this study is to provide validation for a new altitude DCS risk assessment model developed at the AFRL. This model is expected to provide the software for a USAF predictive/real-time decompression computer. In addition, at the completion of this study, data from these altitude subject-exposures will be added to the AFRL Hypobaric DCS Database to further update the existing model. A human use protocol was written, submitted, and approved by the AL/ACHE and AF/SGO, in support of this study. Human subject-exposures were begun in July and are on schedule to be completed in two years.

Staged Decompression with an Argon-Oxygen (ARGOX) Breathing Mixture to 3.5 psia Study

The objective of this study is to provide data on DCS risk levels using a combination of procedures hypothesized to optimize denitrogenation. The procedures are designed to test a novel staged decompression procedure to 3.5 psia while breathing 100% oxygen, or a mixture of oxygen and argon, and include use of exercise-enhanced prebreathe. The data would provide a scientific basis for future decisions regarding ways to improve mission accomplishment during extravehicular activity (EVA) and military spaceplane operations. A proposal in response to the NASA Research Announcement (NRA 96-HEDS-04) was prepared and delivered. A human use protocol was written, submitted, and approved by the AL/ACHE and AF/SGO, in support of this study.

AFRL Hypobaric DCS Research Data Acquisition System

An on-line data acquisition system was designed to display and record physiologic and altitude chamber data in real-time. Components of the system were purchased and installed. These components include a Umax SuperMac S900 6042/225 computer with MacLab 16s hardware and software, two Princeton EO17 color monitors, an Xclaim VR video capture card, an Epson stylus 800 color printer, JBL speakers, a Mediastore Extreme read/write CD-ROM with an Iomega Jaz drive, a CB Science ETH200 bridge amplifier, a CB Science ETH250 bridge/bio amplifier, a MacLab galvanic skin response amplifier, a Nonin 8600 pulse oximeter, an Ambulatory Monitoring Respitrace System, and a Marquette M-100 mass spectrometer.

The Effect of Ascent Rate to 40,000 feet on DCS Incidence

The objective of this study is to determine the effect of altitude ascent rate on DCS incidence. In addition, data will also be provided to determine the DCS risk for human exposure to 40,000 feet. This study will provide crucial data for the Air Force F-22 program. A human use protocol was written and submitted in support of this study.

Equipment and Technical Support

An HP SONOS 1000 Echo-imaging System was provided for data acquisition during hypobaric decompression studies. Technical support was provided, including data entry (DIN A003 and DIN A011) and subject training/support (see Human Subject Acquisition, Section 2).

26.21 Serotonergic Regulation of the Circadian Clock

The contractor shall conduct a pharmacological characterization of the serotonin receptors in the suprachiasmatic nuclei of the hamster, rat and mouse using a combination of membrane binding and quantitative receptor autoradiographic techniques.

The contractor shall employ a variety of selective lesioning techniques.

(1) Determine the cellular location of 5HT1A, 5HT1B, 5HT2C, and 5-HT7 receptors in the SCN. and (2) determine the extent to which each receptor species is responsible for the actions of serotonin on the circadian clock, including the modulation of photic responses.

The contractor shall characterize the circadian patterns of expression of the serotonin receptor species, 5HT1A, 5HT1B, 5HT2C, and 5-HT7 in the hamster, rat and mouse SCN. Expression will be determined by quantitative insitu hybridization and on SCN micropuches using the quantitative reverse transcriptase polymerase chain reaction (RT-PCR) technique according to procedures developed at the BRAIN Research Institute . (DIN: A004, A007, A010, A017)

The contractor shall at the conclusion of the task, deliver a Final Report in a form suitable for publication in a peer-reviewed scientific journal. This report will summarize all test results obtained and conclusions drawn from the research effort. In addition, the contractor shall deliver to the Government laboratory all laboratory notebooks, autoradiograms, histological materiel, computer data files, computer printouts, graphs, drawing, calculations and other physical products of the research activity. (DIN: A004, A005, A007, A010 , A016, A017, A019)

Accomplishments

Research reports (DIN A005, DIN A009, DIN A010, and/or DIN A016) from this effort include:

Pickard GE, Scott PA, Riberdy AF, Weber ET, Rea MA. Presynaptic 5HT1B receptors mediate serotonergic inhibition of photic responses in the hamster suprachiasmatic nucleus. 5th Meeting Soc. Res. Biol. Rhythms. 1996;50:52.

Abstract: "The SCN receives a robust serotonergic (5HTergic) innervation from the mesencephalic raphe which regulates the response of the circadian clock to photic stimuli through 5HT1A/7 receptors in the SCN most likely via a postsynaptic mechanism (Rea et al., 1994). 5HT also regulates the photic response of retinorecipient neurons in the superior colliculus(SC) through 5HT1B receptors, although these receptors in the SC are located presynaptically on retinal afferent terminals (Boschert et al., 1994: Mooney et al., 1994). We hypothesized that 5HT may also regulate photic responses in the SCN through a similar 5HT1B presynaptic mechanism. To test this hypothesis, we investigated the effects of systemic and intracerebral administration of the 5HT1B agonist, TFMPP, on light-induced phase shifts of wheel-running activity and c-fos expression in the SCN. The effect of orbital enucleation on the binding of [125]-ICYP in the SCN and SC and also assessed by quantitative autoradiography. Systemic administration of TFMPP 30 min prior to light stimulation (20 lux white light for 10 min) at CT 14 and CT 19 inhibited light-induced phase shifts in wheel-running activity in a dose-dependent manner with complete inhibition of phase shifts observed at a dose of 5mg/kg. TFMPP alone did not alter the phase of the activity rhythm. Administration of the 5HT 1A antagonist, (+)WAY100135 (5mg/kg), or the 5HT 2A/2C antagonist, mesulergine (5mg/kg). 30 min prior to TFMPP injection, did not alter the ability of TFMPP to inhibit light-induced phase advances at CT19. Local infusion of 1mM TFMPP (0.3 µl) into the SCN region via chronic indwelling cannula 10 min prior to light stimulation significantly inhibited light-induced phase shifts at CT 19 compared to saline injected controls ($p < 0.001$). Systemic administration of TFMPP also inhibited Fos expression in the SCN in a dose-dependent manner. Bilateral orbital enucleation significantly reduced [125]-ICYP binding in the ventral SCN (35% reduction) and the superficial layer of the SC (53% reduction). Taken together, the results are consistent with the interpretation that 5HT1B receptors are located presynaptically on retinal terminals in the SCN and that activation of these receptors inhibits photic input to the circadian clock. Thus, 5HT tone in the SCN may play an important role in the regulation of circadian phase by serving to modulate the response of the circadian clock to photic stimuli."

Pickard GE, Weber ET, Scott PA, Riberdy AF, Rea MA. 5HT 1B receptor agonists inhibit light-induced phase shifts of behavioral circadian rhythms and expression of the immediate-early gene c-fos in the suprachiasmatic nucleus. J. Neurosci. 1996;16:8208-20.

Abstract: "The suprachiasmatic nucleus (SCN) is a circadian oscillator and a critical component of the mammalian circadian system. It receives afferents from the retina and the mesencephalic raphe. Retinal afferents mediate photic entrainment of the SCN, whereas the serotonergic afferents originating from the mid-brain modulate photic responses in the SCN: however, the serotonin (5HT) receptor subtypes in the SCN responsible for these modulatory effects are not well characterized. In this study, we tested the hypothesis that 5HT1B receptors are located presynaptically on retinal axon terminals in the SCN and that activation of these receptors inhibits retinal input. The 5HT1B receptor agonists TFMPP and CGS 12066A, administered systemically, inhibited light-induced phase shifts of the circadian activity rhythm in a dose-dependent manner at phase delay and phase advance time points. This inhibition was not affected by previous systemic application of either the selective 5HT1A receptor antagonist (+)WAY 100135 or by the 5HT2 receptor antagonist mesulergine, whereas pretreatment with the

nonselective 5HT1 antagonist methiothepin significantly attenuated the effect of TFMPP. TFMPP also produced a dose-dependent reduction in light-stimulated fos expression in the SCN, although a small subset of cells in the dorsolateral aspect of the caudal SCN were TFMPP-insensitive. TFMPP (1mM) infused into the SCN produced complete inhibition of light-induced phase advances. Finally, bilateral orbital enucleation reduced the density of SCN 5HT1B binding sites. These results are consistent with the interpretation that 5HT1B receptors are localized presynaptically on retinal terminals in the SCN and that activation of these receptors by 5HT1B agonists inhibits retinohypothalamic input."

26.22 Aeromedical Research and Evaluation

The contractor shall conduct and provide support for test and evaluation of aeromedical evacuation medical devices and systems such as frequency converters, cardiac monitors/defibrillators/pacers, infusion pumps, oxygen systems, ventilators, transport systems, physiologic monitors and suction machines. Provide test data and information, including methods of analysis, test results, and conclusions. Prepare and deliver interim and technical reports on assigned projects. (DIN: A0010, A016, A107)

The contractor shall provide on site engineering expertise for technical development of medical devices, determine support equipment needed for appropriate evaluation, provide engineering expertise for testing conducted by technicians, recommend modifications of devices to meet MIL-STD specifications, and directly communicate with the customer's engineering staff.

The contractor shall provide necessary supplies, airworthiness laboratory equipment, and flight approved equipment. This may include but is not limited to: data acquisition subsystems, transducers, and physiological simulators.

In addition, the contractor shall provide evaluation of the Uni-Vent Eagle 754M portable, self-contained ventilator system. During the original testing of this unit excessive leakage current to ground was found.

The contractor shall provide evaluation of the Life Support for Trauma and Transport (LSTAT) Model 9601

The contractor shall provide evaluation of the Propaq Encore manufactured by Protocol Systems, Inc for compatibility with aircraft systems. This unit failed to meet some of the EMI requirements during initial testing and must be re-evaluated for use on small aircraft.

Accomplishments

KLSI conducted and provided support for test and evaluation or technical consultation for the following aeromedical evacuation medical devices/systems (NOTE -- Technical reports have been or are being published for all completed projects and acknowledgment for contractor support under this contract is given.):

1) C-17 Oxygen System

2) Avionics Instruments, Inc., Model 4B3500-1A-MV-735, Frequency Converter

3) Energy Technologies, Inc., Model ET100050F2-3P/4.5, Frequency Converter ***

4) Hewlett-Packard, Model CodeMaster 100, Portable Defibrillator

5) Diametrics Medical, Model IRMA, Portable Blood Gas Analyzer ***

6) Represented Brooks AFB, Aeromedical Research, as a Technical Evaluation Panel Member evaluating transport ventilators for a Veterans Administration solicitation bid.

7) IVAC Medical Systems, Inc., Model Medsystem III, Infusion Pump

8) IVAC Medical Systems, Inc., Model Signature Edition II, Infusion Pump ***

9) BCI International, Model 3303, Pulse Oximeter

10) BCI International, Model 3304, Pulse Oximeter

11) Impact Corporation, Model 326M, Suction System

12) Represented Brooks AFB, Aeromedical Research, as a technical consultant in the preparation of an MOA between the Air Force and US Army.

13) Lifeport Corporation., Model Aerosled Plus, Patient Transport System

14) Compose Inc., Model Apex II, Data Collection System

15) Impact Corporation., Model 308, Suction Pump

16) i-STAT Corporation, Model i-STAT, Portable Clinical Analyzer

17) Evaluated two candidate field anesthesia units for the Defense Medical Standardization Board (DMSB)

18) OHMEDA Corporation, Model 3800, Pulse Oximeter *

19) Mine Safety Appliance (MSA), Model MINIOX 3000, Oxygen Monitor *

20) Spectrum 500-LP (Military Version) Model 2500, Air Ambulance Life Support System

21) Design of Cart for Extracorporeal Membrane Oxygen (ECMO) System

22) Laerdal Medical Corporation, Model Heartstart 911, Automatic External Defibrillator **

23) International Biomedical, Inc., Neonatal Transport Incubator **

24) Crown Therapeutics, Pressure Mattress ***

25) Nellcor Puritan Bennett, Ventilator ***

26) Schiller, Model ARGUS TM-7, Universal Patient Monitor **

27) Allied Healthcare, Model Autovent 3000, Ventilator ***

28) Micromedical Inc., Model BIOLOG, ECG Monitor ***

29) AVL Scientific Corporation, Model OPTI-1, Blood Gas Analyzer ***

30) Nonin, Model 8600, Pulse Oximeter ***

31) Newport Medical Instruments, Inc., Model E100i, Ventilator ***

32) Zoll Medical Inc., Model PD 2000, Cardiac Monitor/Pacemaker/Defibrillator System

33) McGaw Inc., Model Horizon, Infusion Pump ***

34) Ceotronics, Model TC-917, Wireless Headsets *

35) Physio-Control, Model LP-500, Automatic External Defibrillator *

36) Baxter Healthcare Corporation, Model AS50, Auto Syringe **

37) Unitron Corporation, Medi-Vac PPS Model PS-95-448-1, Frequency Converter **

38) Nellcor Corporation, Model N-500, Continuous Noninvasive Blood Pressure Monitor ***

39) Civil Reserve Air Fleet (CRAFT), B-767 Aircraft, Oxygen System

40) Technology Transfer, Inc., Model PAM, Portable Cardiac Monitor ***

41) Medical Research Laboratories (MRL), Model 360 SLX, Portable Cardiac Monitor/Defibrillator

42) Zoll Medical Inc., Model PD 1400, Cardiac Monitor/ Defibrillator

43) SAI Technology, SAIC, Model (M3), Mobile Medical Monitor ***

44) Physio-Control, Model LP-10-62, Defibrillator

45) Unholtz-Dickie, Vibration Table Upgrade

46) Consultant to Systems Program Office Responsible for the development of the Spinal Cord Injury Transport System (SCITS) *

47) Protocol Systems Inc., Model (s) 106 EL, 206 EL and 206 EL (EMI Modified)

48) US ARMY Program, Life Support for Trauma and Transport (LSTAT), Model 9601 *

49) Impact Corporation, Model 754, Portable Transport Ventilator *

50) Heartstream, Model Fore Runner, Automatic External Defibrillator **

51) US ARMY Program, Prototype High Volume Infusion Pump

* Identifies projects in work

** Identifies projects waiting to be worked (i.e. CRADA/legal documents not signed)

*** Identifies projects which will not be completed

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